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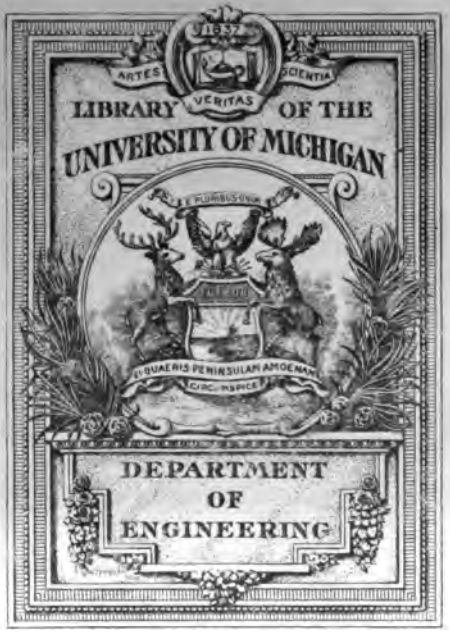
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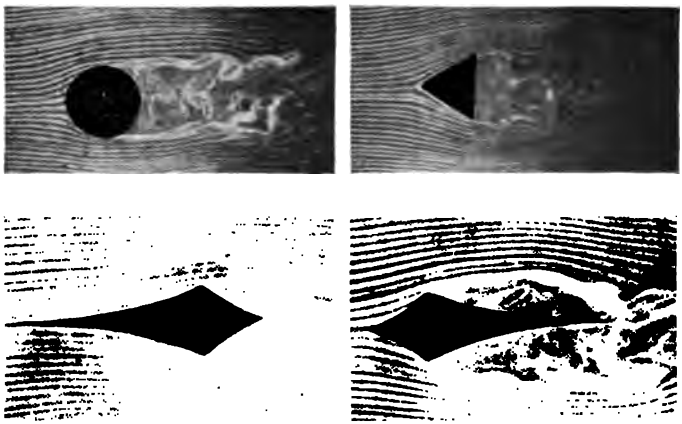
For Amateurs







Cross-section of pelican's wing imbedded in a block of paraffine. Note the comparatively small space occupied by the bones, which consequently cannot furnish the sole reason for the enormous thickness in this section equivalent to about one-eighth of the chord. See Pages 59 and 60.



Aeroplane Designing

For Amateurs

A Plain Treatment of the Basic Principles of Flight Engineering—Including Heretofore Unpublished Facts Concerning Bird Flight and Aerodynamic Phenomena

By

Victor Lougheed

Founder Member of the Society of Automobile Engineers
Author of "Vehicles of the Air"



Eighty-two Illustrations

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DEDICATED

To the pioneer, to whose rare vision and splendid genius it was given, more than to any other, to wrest from the inscrutable mysteries of force and matter the greatest marvel of engineering perfection and practical significances, which ever has loomed upon the horizon of human endeavor—

To Professor John James Montgomery, whose lifelong devotion and final martyrdom to the tremendous problems of aerial navigation will be a never-forgotten inspiration to those who were honored with his steadfast friendship, and will remain an unfailing example to the few in each generation who ignore the discouragements of doubt and dare the summits of human achievement.





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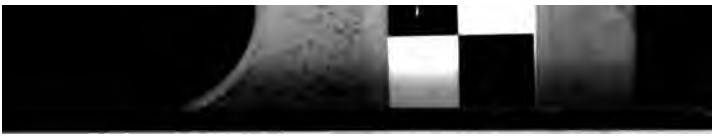
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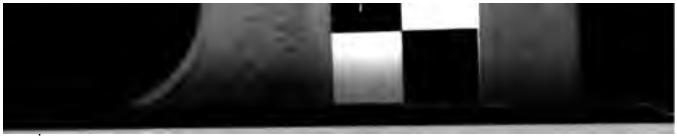


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PREFACE

Being possessed of certain special information, some original and some gained from fellow experimenters, and much derived from an authority whose work so far has been but little exploited or understood, despite a priority, completeness, and standing that probably destine it to take finally the very highest rank in this department of science, the writer feels that it is now due to other investigators that at least a part of this information be released for the benefit of aviation development in general.

Since it is upon knowledge of the laws of fluid movements that all progress in aviation must depend absolutely, it probably will be conceded that the only investigations ever made that offer even a well-substantiated claim to the complete formulation of these laws, are entitled to at least such credence as may properly repose in prima facie evidence and demonstration. And in thus confining himself to explanations based upon the only instances of really exhaustive scientific analysis existing in this field, instead of attempting to correlate the complex and often random and uncertain conclusions of even the most successful empiricists, the author believes that whatever may be lost in the way of a conventional treatment of the subject will be gained in the interest that always attaches to new information.

Furthermore, believing as he does in the soundness of certain researches into the laws underlying the movements of elastic fluids, and being unable to disregard the importance of the interrelations between these movements and the forms of suitable wing surfaces, the author will rely frankly upon his knowledge of these researches in his discussions of aeroplane operation, showing reasons for his dismissal of such conclusions as are at variance with what he knows to be established facts, and in the cases of machines of successful types making it appear that their success or non-success is invariably in direct proportion to the degree in which they conform to or deviate from natural laws, the existence of which is not disproved by ignorance of them.

With this preliminary explanation, no further apology seems necessary for the method used in approaching the subject.

In the course of much of what follows, the author will take the liberty of quoting more or less frequently from a heretofore unpublished paper by Professor John J. Montgomery, on "Soaring Flight," which was written in 1893, and presented to the consideration of Mr. Octave Chanute in 1895.* Because of the brevity with which certain of the conclusions in this paper are stated, and an occasional manner of explanation that is somewhat incomplete for the untechnical reader, the writer will supplement with his own explanations much that in the original paper is left too complex or in too brief form for popular understanding.

In doing this, only what is directly quoted without change will be placed in quotation marks, but it is to be understood that much of the rest of the matter herein is more or less **directly borrowed, with or without paraphrase or amplification, from what the writer sincerely believes to be one of the most illuminating and profound contributions ever made to the literature of this enthralling subject.**

Before proceeding further, the writer proposes to preface his statement with a brief history of the researches upon which so much of his information is based, believing that Professor Montgomery's work in the investigation of aeronautical problems is on the face of it worthy of taking the highest rank, because of its priority as well as because of its soundness.

A graduate of St. Ignatius College, at San Francisco, in 1879, he had been attracted even then to the subject of aerial navigation, when a move on the part of his family from Oakland to San Diego, California, soon after resulted in the hills around the little town of Otay, just north of the Mexican line, becoming the scene of experiments that antedated even Lilienthal. In passing, it is interesting to remark that these first struggles with the then tremendously difficult problems of the air were surrounded by conditions of the most discouraging character—so much so that none

* It possibly is well to mention that these dates are absolutely *authenticated by many* witnesses, as well as by the sworn affidavit *of Dr. Chanute, and* that the ultimate result of Professor Montgomery's researches and conclusions is to a large extent embodied in U. S. Patent No. 831,175, issued on September 18, 1906.

familiar with the soul-tormenting adventures of the youthful Montgomery, warring valiantly in the face of poverty, derision, and every other imaginable handicap, so many years in advance of his time, with a mystery that until recently had baffled the foremost engineers of the world, possessed of the finest and most expensive facilities of the age, and which still is invested with profound misunderstanding, can ever forget the picture of the lonely and misunderstood boy, dubbed crazy by his associates, suffering from a diffidence naturally born of the ridicule to which he was subjected, and further handicapped by the remoteness of the locality that was the scene of his experiments—all so characteristic of the first struggles of genius, which too often after achieving its results goes down unrecognized by contemporaries, to become famous only in the eyes of subsequent generations, and after the lapse of many years. In Professor Montgomery's case this has particularly tended to occur, because of the failure of his early work to be conducted under conditions that could permit its consideration and appreciation by the few scientists in the world at that time interested in the subject of flight. To those fortunate in possessing his acquaintance, he was known as the most unassuming of men —one who concealed a most wonderful fund of information, and a theoretical and practical engineering ability of the rarest order, behind a personality of the utmost modesty and good nature.

Like most of his fellows in aeronautical researches, Montgomery of course commenced wrong—his first attempt being a flapping-wing machine that in one experiment convinced its designer that success was not to be found in this direction. This was soon followed, in 1884, with the machine sketched in plan in Figure I—a more or less arbitrary copy and enlargement of a gull's wings, with longitudinal control by vertical movement of the flat tail shown, and lateral balance maintained by shifting of the operator's body. Though this machine was built about eight years before the first gliders of Lilienthal, it possessed in common with them the important feature of wing curves flattened from center to tip —a feature of design that has been almost neglected by more recent experimenters though it will hereinafter be shown to be of the utmost importance to efficient results. With this machine one 600-foot glide, keeping close to the slanting su

face of a hillside, was accomplished near Otay, California, in 1884. In a second attempt, while balancing the machine in a light wind in preparation for a glide, a gust of wind suddenly raised it with the operator to a height of perhaps ten

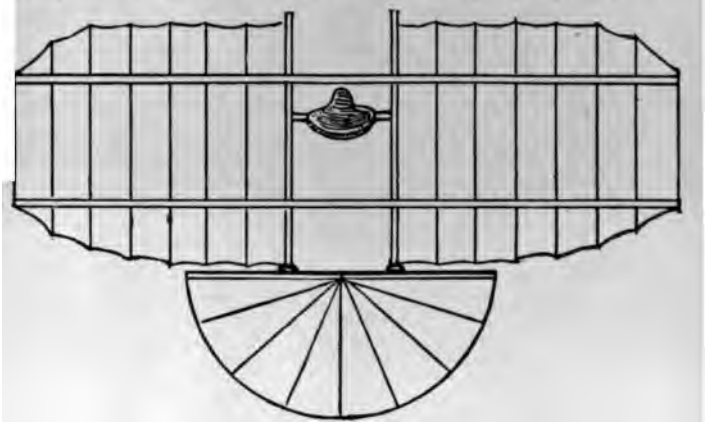


Figure I.—First Montgomery glider, built in 1884, and with which a 600-foot glide was accomplished near Otay, California, during that year. This machine was described, and its performance noted, in Chanute's "Progress in Flying Machines," published in 1891-1894.

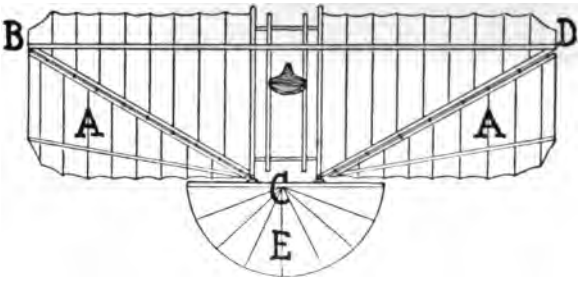


Figure II.—Plan view of second Montgomery aeroplane, built in California in 1885, and also described in "Progress in Flying Machines." Note the manner in which half of each wing at AA is hinged along the lines BC and CD, aileron like, as a means of maintaining lateral balance. The tail E is for up-and-down steering.

or fifteen feet and then slammed it down on the tip of one wing, with the result that it was smashed beyond repair.

Though fair sustention per unit of area was secured with this first machine, due to the rather sound policy of copying

a bird, Montgomery followed with the absurd mistake of concluding that the down curve to the front of the bird's wing was "against nature," with which idea in mind his second machine, shown in Figure II, was built with flat surfaces. In a degree, however, he compensated for this mistake by seeking much-needed lateral balancing means through the use of the hinged rear portions to the wings shown at AA, adapted to bend down along the hinges, BC and CD. A flat

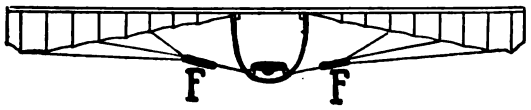


Figure III.—Front view of second Montgomery glider, showing at FF the springs originally used to stay down the ailerons in such manner that they could yield automatically to excessive air pressures.

tail, like that used in the first machine, was provided at E. At first the aileron-like rear wing portions were stayed down as shown in the front view of the same machine in Figure III, by the springs, FF. Incidentally it is to be remarked that this staying down constituted in a sense an equivalent of curvature in the main wing surface. In the course of a few trials, it was found that the idea of yielding springs at FF, in the use of which it was intended that wind gusts would force up one side or the other of the wing ends, thus offsetting the tendency to tip over, was ineffective for the purpose. This being the case, the plan illustrated in Figure IV was substituted, in which G is the operator's seat, resting on the rocking bar H, suspended in the ribs II to the frame J, and provided at its rear end with the upturned portion K, at the top of

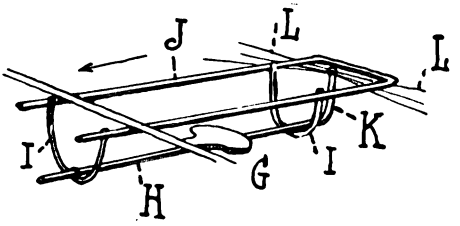


Figure IV.—Second control used on Montgomery ailerons. In this the seat G is fixed rigidly to the bar H, which rocks in the frame ribs II, which are themselves secured to the main frame J. To the upturned rear end of H, at K, are attached the groups of wires LL, one group to each wing, so that as the rider leans to one side or the other the wings are unsymmetrically manipulated.

which were fastened the two groups of wire LL, one to each aileron.

On the face of it the point of attachment was too close to the wing surfaces to allow sufficient down angle to the pull on the ailerons, but the young Montgomery seems to have missed realizing this until he made an actual trial. This trial resulted immediately in a change to the construction shown in Figure V. In this the operator sat across the double control bars NN, pivoted at OO and PP, with the wires attached at QQ, so that throwing his weight upon one side or the other drew down the aileron on the side that tended to lift.

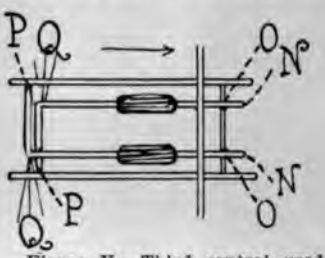


Figure V.—Third control used on Montgomery ailerons. In this the seat is constituted of the two pads, one on each of the bars N N, each of which is hinged, at O and P, so that as the operator rocks his body the groups of wing wires at Q Q are correspondingly drawn down or let up.

This proving still a rather clumsy and unsuitable scheme, that shown in Figure VI was built but never applied to the machine, because by this time it was found that no sufficient lift could be had with the flat surfaces, so the machine was discarded as a failure. In this control the stirrups RR served to revolve the wheel S, fixed on the same shaft as the pulley T, which worked the ailerons by the wires UU. Profiting by the experience gained so far, Montgomery's next machine was that illustrated in Figures VII, VIII, and IX, in which return was made to the bird form, the machine being a quite accurate copy in both rib curvature and in front sinuosity of the wings of a turkey buzzard. Unfortunately, however, in this machine Montgomery saw fit to

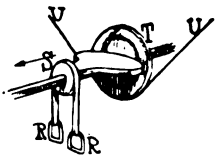


Figure VI.—Fourth aileron control of Montgomery glider. This thoroughly mechanical arrangement was built but not applied, because the machine for which it was intended had flat surfaces and therefore would not lift. The seat and the pulleys S and T were all rigidly fastened to the bar beneath them, so that rocking of the operator's body, made additionally effective by the stirrups RR, would move the wires U U.

discard the excellent idea of hinged ailerons, substituting for them pivoted wings, so arranged that the wings could be rocked similarly or dissimilarly by the handles VV, the former manipulation relieving him of the necessity of having a controllable tail at W. With this machine a few short glides were accomplished, but none as successful as that with the very first machine, illustrated in Figure I.

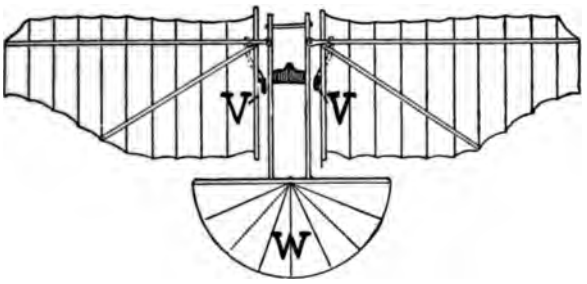


Figure VII.—Plan view of third Montgomery machine. In this machine the wings were pivoted in their entirety, so that by moving the handles V V the operator could rock the wings either oppositely or together. Obviously the latter movement eliminated any necessity for hinging the tail W.

One of these three machines is still in existence, as also are parts of the others, and all of them were seen by many people, some of whom are still living in the neighborhood of San Diego, California, to-day. Also, they were described

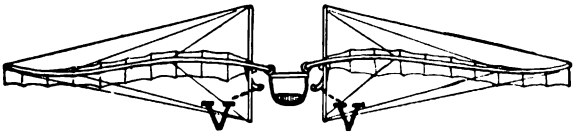


Figure VIII.—Front view of third Montgomery machine. The position of the handles V V are well shown in this illustration, as also are the curvature and sinuousity of the wings, which were patterned after those of a turkey buzzard.

at some length, though not illustrated, on pages 248 and 249 of Chanute's "Progress In Flying Machines," written in 1894.

Discouraged by the fact that the result of his experiments had been the construction of a worse machine than the one with which he had started, Montgomery for the time being

gave up the idea of further experimenting with man-carrying machines, and came to the conclusion that, the laws of aerodynamics being unknown, and the whole subject being one of the utmost difficulty, the one rational road to success was in scientific investigation and analysis of these laws with a view to their resolution and formulation, as an absolute prerequisite to any real success with man-carrying apparatus.

From the time of this conclusion dated a period of consistent researches, which for priority, originality, and the quality of their theoretical deductions and practical results have been approached by no subsequent investigator except as the development of light-weight motors has enabled those who were first in borrowing these from automobile engineering to achieve sustained in the place of gliding flight.



Figure IX.—Control handle and wing bracing on third Montgomery glider.

For some six years, from 1886 to 1892, Montgomery's researches were carried on, sometimes interrupted by other affairs and again persisted in most assiduously when time permitted. The first result was made public in the brief paper which was read at the Aeronautical Conference at the World's Fair, in 1893, and portions of which are quoted elsewhere herein.

In addition to this, the paper referred to on Page 14 was presented to Dr. Chanute in 1894 or 1895, as a more complete summary of Montgomery's conclusions.

With all of the work necessary to the construction of practical aeroplanes thus completed in the middle nineties, it was not until 1903 and 1904, eight or nine years later, that Montgomery was financially and otherwise able to build at first models and subsequently man-carrying gliders, which proved most amazingly the correctness of his conclusions—a correctness further proved by the in some cases accidental and in other cases deliberate following of his theories by other aeroplane constructors.

An interesting fact deserving of mention is, so completely out of touch was Montgomery with the few others in the world who were giving serious attention to aeronautical problems, that he was compelled to pursue an almost independent course with practically no help from, and with only the most *vague and superficial* knowledge of contemporary European

and other investigations, such as those of Lilienthal, Pilcher, Langley, Ader, and others of greater or less achievements.

In 1903 Montgomery concluded experiments with the three models illustrated in Figures X, XI, and XII. In all of these there was the application of certain definite principles.

First was the use of proper wing curvatures to secure a maximum sustention with a minimum forward resistance, by a proper modification of the wing curvatures from center to tip; and second was the securing of automatic equilibrium

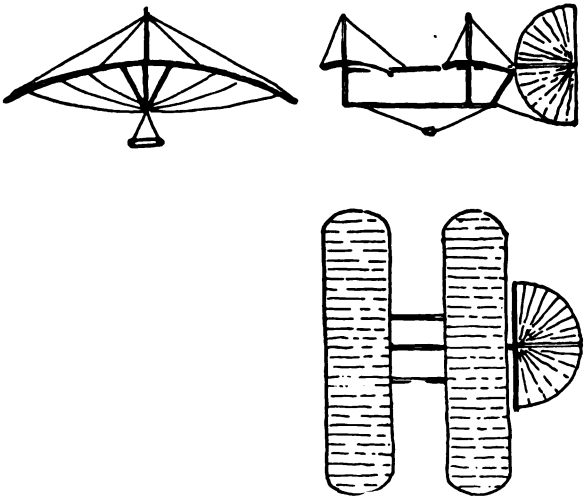


Figure X.—Fourth Montgomery model, built in 1903 and subsequently enlarged to man-carrying size, in which form it constituted the basis of the remarkably successful flights, in the Santa Clara valley and elsewhere in California, during 1904 and 1905.

by the principle of a large vanelike fin at the rear of the machine, so that any tendency to turn over, either by the impact of a wind gust or a sidewise inclination of the machine, must immediately result in its front or rear portion skidding sidewise, so that the tendency to tip over would be terminated by a continuance of the glide in the direction of the fall.

The beautifully constructed parts of one of these models are at present in the writer's possession, and from the sketches *given in* Figures X, XI, and XII, any competen

engineer can readily reproduce them and determine for himself their great perfection and marvelous equilibrium.*

The machine illustrated in Figure X was designed to combine a maximum area with a minimum weight, and to afford always a parachute-like automatic settling, right-side up, even when adjusted not to make much lateral movement. That



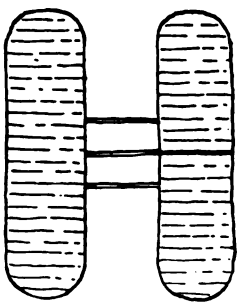


Figure XI.—Fifth Montgomery model. Never built as a large machine, but experimented with as a compromise between the types shown in Figures X and XII.

shown in Figure XII was designed more for use with constant manipulation of controlling means, while that shown in Figure XI was intermediate in both its form and its functioning between the other two.

Of the two last, neither has been as yet built to a man-carrying scale with motors, though Montgomery considered

* The writer knows of a recent case in which a young man living in Salinas, California, built a copy of the machine shown in Figure X with a ten-foot span, and, loading it with 25 pounds of rocks, secured in calm air a glide of a mile and a half from a height of 150 feet!

that illustrated in Figure XII the furthest developed, and the best adapted for use with power propulsion.

Having concluded his experiments with models, Montgomery commenced in 1904 experiments with a large copy of the machine illustrated in Figure X, whereupon, with less actual experimenting in the air than was ever done by any other successful investigator, but equipped with more knowledge of the laws of aerodynamics than was possessed by

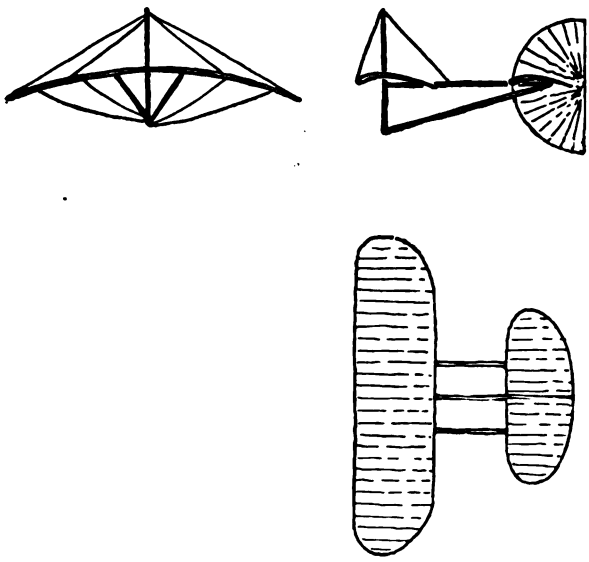


Figure XII.—Sixth Montgomery aeroplane. Exhaustively experimented with in model sizes during 1903 and 1904, and decided upon as the most suitable for use with power propulsion.

any other investigator, he rapidly progressed to a point where, on April 29, 1905, he was able to send up from Santa Clara, California, in the presence of fully fifteen thousand people, including many western newspaper men, one of his tandem monoplanes, a large copy of the model illustrated in Figure X, attached to a balloon and ridden by an intrepid parachute jumper, Daniel Maloney, who at a height of four thousand feet cut loose from the balloon with the forty-five-pound *glider* and accomplished a safe descent to earth, t

the course of which he exercised a degree of control and performed steering and diving movements that are yet to be outclassed by the finest volplanes or other maneuvers of the most accomplished modern aviators.

This flight was terminated by a perfect descent on a predesignated spot, Maloney landing on his feet, with his hands supporting the machine, with so slight a jar that he did not even go to his knees.

The correspondent of the Scientific American, in the issue of that periodical published on May 20, 1905, declared that "an aeroplane has been constructed that in all circumstances will retain its equilibrium and is subject in its gliding flight to the control and guidance of an operator." Octave Chanute characterized the flight as "the most daring feat ever attempted," and Alexander Graham Bell had no hesitation in asserting that "all subsequent attempts in aviation must begin with the Montgomery machine."

Similar performances were repeated some fifty or sixty times in the course of exhibitions that Montgomery gave around California, in an effort to secure funds for the continuance of his experiments, and in 1906 he was just at the point of making a gliding flight across the Santa Clara Valley from a station on the side of Mt. Hamilton, near the Lick Observatory, over four thousand feet above sea level, when his work was brought to a standstill by the destruction of his workshop and apparatus at Santa Clara College, in the



to release his hold upon the steering wheel and fall sidewise in the frame of the glider. This shifting of his weight and deranging of the control caused the machine first to dart up and then descend. It landed rather lightly on the right wing tip, but just as it struck a gust caught the left side and quickly turned the aeroplane over, with the result that Montgomery fell upon his head and suffered seemingly rather slight injuries, from which, however, he died two hours later, conscious to the last. No bones were broken, nor was there any bruising or maiming beyond a slight cut under the nose, and the presumption is that the trouble was primarily attributable to a slight attack of vertigo, to which Montgomery was subject, and the serious result from so slight a fall was chiefly due to the Professor's weight in combination with an unhappy mischance that would scarcely have occurred again in a hundred similar accidents.

In concluding these prefatory remarks, in addition to giving credit to Professor Montgomery for the important elements contributed by him to the science of aerodynamics, the writer wishes to express his particular acknowledgment to Ward Leathers for his work in preparing the illustrations used herein.

And, also, the writer wishes to express his thanks to the many fellow enthusiasts who in one way and another showed their interest in his "*Vehicles of the Air*," and to whom, as to others, he ventures to hope that the present small volume may prove in some measure helpful and informing.

VICTOR LOUGHEED.

CHICAGO, *November, 1911*





INTRODUCTION

At the time this is written, the author feels that the moment has arrived for a change from the accustomed type of flying-machine handbook, which because of the difficulties, uncertainty, and ignorance that have in the past surrounded aeroplane design, and on the plea that these principles were not sufficiently defined or established to permit their clear formulation, has commonly evaded explanation of the basic principles at the basis of this branch of engineering.

This view, however correct and well justified in the past, is one to which the writer (and he believes many others) will properly take vigorous exception at the present time.

Less than three years ago aeroplane design, judged by its achievements, may be said to have been in a doubtful and completely experimental condition. At that time probably not ten persons in the world had been off the ground in an aeroplane, there were only four aeroplanes known that would really fly, none would go faster than 40 miles an hour, no sane aviator dared to go aloft in a breath of wind, no aviator had been 200 feet high, and it is doubtful if the total distance rather precariously flown up to that time exceeded a few hundred miles.

At the present writing, one man has flown continuously for over eleven hours, another has flown 500 miles in 6 hours and 50 minutes, several men have flown continuously for over five hours, 13 over four hours, 68 over three hours, and 201 over 2 hours, while one-hour flights have become so numerous as to cease to be chronicled even in the aviation magazines, there being 667 one-hour flights officially recognized by the Federation Aeronautique during the six months from January 1 to July 31, 1911. The English Channel has been crossed and recrossed fifty times; oversea flights of a hundred miles more and less have been made; an aeroplane has flown from London to Paris in four hours, without a landing; the Alps have been surmounted; the altitude record stands at over two and one-half miles; repeated cross-country journeys, up to 4500 miles in length, have been made at average speeds

ranging up to 157 miles an hour and better, and many flights have been accomplished in strong winds.

At least three European aeroplane builders have sold over 500 machines each, and some two thousand aeroplane pilots have made a total of much more than 500,000 miles in the course of the qualifying flights necessary to secure the certificate of the Aero Club of France. Certainly not less than two million miles is the aggregate of all aeroplane flying to date, while it is conservatively estimated that present mileage totals about 65,000 a week for the whole world. Over 10,000 persons have made passenger flights that are matters of definite record, and fully forty-five million dollars is invested in the industry in Europe alone—mostly by famous automobile companies. In the army budget for 1912, the **French government alone has appropriated nearly three and one-half million dollars for the aeroplane corps.**

Contrary to a still widely current impression, this development is far from being simply a mere matter of more practiced aviators; it inheres absolutely in the improvements in, and in the better understanding of aeroplane design, which is now so exact a science that at least a score of the more qualified manufacturers put out machine after machine, each with as absolute assurance of practical and successful operation as prevails in the automobile or in any other established manufacturing business.

Particularly creditable is the progress that has been made in motors—the best aeroplane engines of to-day being in most cases veritable marvels in the way of high power and great strength combined with light weight and ample durability. Just how wonderful this progress is, comes especially home to one when it is realized that one well-known aviation motor capable of developing 100 horsepower for ten hours at a time is one-twentieth as powerful while weighing less than one-thousandth as much as some of the heaviest freight locomotives.

Indeed, so fast and far has aviation-motor design developed, that it is the cause of two rather curious present conditions. The first of these has been the frequent accomplishment of flight by aeroplanes most outrageously ill-designed—rammed through the air with the engineering efficiency of a barn door in a cyclone. The second condition is the fast-increasing tendency to develop more efficiency in aeroplanes rather than



more power in motors, with the almost certain result that the demand for high-power units of light weight will not for many years, if ever, increase beyond what are at present available.

Nevertheless, with all the shortcomings in the best of present-day aeroplanes, these are shortcomings in such details as can admit of improvement only in efficiency, in structural features, and in safe equilibrium and control, rather than in any possible direction towards a revolution in fundamental principles.

It is the one most unfailing lesson of mechanical history that practically all great advances in man's conquest of the forces of nature come as developments, rather than as full-fledged, perfected inventions. The most modern locomotives bear many close resemblances to the very first of their kind. The modern steam vessel differs little except in refinement in details and increase in size from its prototypes of years ago, and a particularly impressive example is the automobile, in almost every detail of which, in its most modern forms, there are to be discovered features closely similar to those of the automobiles of many years ago, built at a time when the self-propelled road vehicle was commonly regarded as the crazy experiment of a few hopeless cranks.

The conclusion forces itself that the time has passed for the freakish in flying-machine design. Even such interesting devices as the helicopter and ornithopter, and most of all, the dirigible balloon, are at the moment regarded as quite out of court by the men best qualified to venture authoritative opinions on the subject. Rightly or wrongly, the author falls sufficiently in with this view to feel warranted in the present volume in excluding these, as properly subject to such consideration as they may merit, under separate cover rather than entitled to treatment in a book devoted to the one type of flying machine possessed of both a definite present and a definitely-developing future—the aeroplane.

The idea of machines, heavier than air, which nevertheless should sustain themselves in the air by the operation of suitable mechanism, is an obvious deduction from the observation of the birds and of flying animals and insects, all of which, quite without exception, are vastly heavier than the tenuous medium that so securely supports them. As a consequence, the earliest conceptions of heavier-than-air flying

machines long antedate the discovery of the balloon, even the various myths and apocryphal accounts of flying men, which have come down from ancient times, being invariably founded upon one or another of the obvious modifications of the mechanical-bird idea.

In later times, and as science and invention have progressed, attempts innumerable have been made to construct successful machines, but with results so uniformly discouraging that the very term "flying machine" was for long a synonym for all that was wild and erratic in inventors' brains and in the way of mechanical perversity. However, complete failures though all the ideas of the early air navigators proved when put to the test, in the revealing light of more recent successes it begins to appear that past failures were due less to insuperable obstacles than to incomplete knowledge—to a failure to understand the essential importance of a very few but most fundamental principles.

The result is that now, as knowledge is accumulated and tested and tabulated in every-increasing increments, and as the great principles are commencing to be wrung from the mazes of indifference and skepticism and ignorance that had so long concealed them, the aerial vehicle is surely and inevitably issuing from the mists of doubt into the realms of the practical.

The history of the aeroplane involves the development of three more or less separate conceptions—the first, the use of gliding surfaces as means of riding down a slant of air from a greater height to a lower; the second, the application of power-operated propelling elements for continuing on a horizontal course or progressing on an upward slant; and the third, the idea of indefinite soaring without power, by the utilization of obscure and little understood, but very evident principles, which are clearly demonstrated to exist in the flight of soaring birds—a mode of flight concerning which there has been much speculation and controversy, and the performance of which is variously ascribed to the phenomenon of rising currents in the atmosphere, to the presence of constantly varying factors in the horizontal movement of winds, and to the operation of laws not yet generally formulated or recognized. Probably the real explanation lies in some measure of sound reasoning that is to be found in both the



Just as water craft probably developed from observation of fish and other aquatic animals, so is the aeroplane fairly to be considered a development from observation of the magnificent effortless flight of the less-common soaring birds.

There is no possible doubt but that the aeroplane is the first successful, and very probably destined to continue the most successful, type of flying machine. Almost everything is in its favor. In its best forms, for example, its inherent stability as a glider may constitute an almost perfect safeguard against the possibility of accident due to motor failure. Moreover, the aeroplane certainly will prove far cheaper to build and safer to operate than any conceivable type of ornithopter, and certainly cheaper than any helicopter that will begin to afford equivalent speeds, lifts, or efficiencies.

As for the balloon, the great difficulties with this attempted means for navigating the air are its inescapably enormous volume, its strict limitations in unit weight of structure, and its great cost.

To ascend, a balloon must be lighter than the volume of air it displaces, and, the weight of a given volume of air being fixed and unchangeable, no possible discovery or invention can open a way of escape from this inexorable factor of the problem. A sphere of air ten feet in diameter weighs almost exactly seventy-six pounds, while a similar sphere of hydrogen weighs something less than six pounds. Consequently, enclosing the hydrogen in an envelope and causing it to occupy the space of an equivalent volume of air manifestly can afford within this considerable bulk a gross lifting capacity of only seventy-six minus six—seventy pounds. Evidently the unlikely discovery of some gas lighter than hydrogen can effect no material benefit, for even should it become feasible to encase a vacuum of the requisite size, as more than one enthusiast has hoped, this could help the sustention only to the extent of the eliminated six pounds of hydrogen. And always within whatever lifting capacity there may be provided must come not only the loads that it is required to convey, but also the weight of the structure and the enveloping material, which it is highly desirable to have far stronger and more rigid than the strongest and most rigid ever likely to be attainable.

From all of which it follows that the best of balloons ar

and are likely to continue, hopelessly bulky and fearfully flimsy, and of only the very smallest lifting capacities in proportion to their size. Held captive or let drift with the wind, they can be made to afford fair security with very limited utility. Provided with motors and propelling means they not only oppose the resistance of enormous areas to rapid motion, but also prove of such fragility that their structure must inevitably collapse under the heavy stresses, should sufficient power within the weight limit ever become available to drive them greatly faster than the maximums of twenty-five or thirty miles an hour that have been so far attained, and which have been time and again proved nowhere near sufficient to combat ordinary adverse winds.

The cost of gas alone for each filling of a large balloon at present places it utterly out of the question for performing commercial service at reasonable cost. About a thousand dollars worth of gas on the basis of the most economical production possible is required for each inflation of a Zeppelin balloon, 443 feet long and 42 feet in diameter, but possessed of a reserve carrying capacity of only five and a half tons. Moreover, no balloon builder as yet has been able within the weight limitation to devise an envelope capable of retaining a filling of gas for more than a limited period—thirty-six hours is the present maximum with dirigibles, and seventy-two with spherical balloons—not to consider the further loss that occurs in the necessary trimming of the craft to desired heights by alternate discharges of gas and ballast—the latter of which, by the way, is a burden to be reckoned with in all estimates of passenger and cargo-carrying capacities.

Concerning the possible and probable applications of aerial vehicles, it is perhaps easier to argue than it is to convince, but at least it will be admitted that such vehicles must find some fields of usefulness, whether it is contended that these fields will prove exceedingly broad or conceded that they must remain exceptionally limited.

In this connection it is perhaps well for the reader to impress upon himself the idea that the aeroplanes of to-day, despite their decidedly remarkable recent successes, must probably bear to the more nearly perfected mechanism of the flying vehicle of the not distant future some such relation *as was* sustained by the automobile of ten or fifteen years

ago to the wonderful, practical, popular, economical, and in every essential respect, successful vehicles that to-day throng the streets and roads of all civilization, and around the construction and improvement of which there has developed a science that in itself constitutes a special department of engineering and an industry in which are invested hundreds of millions of dollars.

It may seem to the casual reader a venturesome thing to predict any similarly extensive development of aerial vehicles. Yet it is to be remembered that even the most accustomed forms of modern transportation—the railway, the steam vessel, the bicycle, the automobile, etc., all had their very inception actually or almost within the lifetimes of people now living, while without exception their development from the experimental stage to the status of unquestioned utility has covered much shorter periods.

Certainly it cannot be escaped or overlooked that the atmosphere as a medium of travel affords more room with less limitations than apply to any other mode of transportation; that it is the medium used by birds for the transportation of considerable weights at great speeds with absurdly small power—many times less than man has available for the same use—and that, though the bird possesses the almost inimitable coördination of animal mechanism, man has nevertheless proved already capable of imitating this coördination and control not only in a considerable degree, but also with remarkable success and safety—the lives so far lost in this growing conquest of the air with heavier-than-air machines being much smaller for given distances traveled than proved the case in the development of apparently much safer means of terrestrial and aquatic travel.





CHAPTER ONE

THE ENGINEERING ASPECT

The cardinal difficulty that from the first has beset the investigator of flight problems has been the almost total lack of accurate data concerning the laws of elastic fluid movements.

In the words of a standard technical work of the highest authority, "the laws of fluid movements, and particularly of elastic fluids, are exceedingly complex, and so far have defied analysis."

This statement, derived from so highly-regarded a source, may be accepted as a fair measure of the general understanding even among engineers concerning this subject.

Yet it is upon these supposedly-unformulated laws of the movements of elastic fluids that all aeroplane action must depend, and to which all aeroplane design must relate. Obviously too, it is only as these laws become understood that aeroplane design can become the exact science it must become before aviation can be said to have developed into a branch of engineering from its present status as chiefly a field for experimenting and empirical investigation.

SOURCES OF DATA

Air in motion possesses properties that are very little understood, the laws of its dynamic actions and reactions not having been generally investigated or formulated. Particularly with reference to the operation of flying machines is this the case. Indeed, more than one of the world's foremost physicists, even in comparatively recent years, has positively declared aerial navigation to be impossible, basing his conclusions upon difficulties encountered in reconciling the idea of man flight with established hypotheses of aerodynamics.

Air, possessing almost perfect elasticity in addition to its weight, fluidity, and other qualities, cannot be set in any but the most simple movements without occasioning a multitude of resultants that are so utterly complex and involved as

almost to defy analysis. The result is that even such comparatively simple phenomena as those of the movement of air in pipes and in jets are only understood in a general way, while the work of most investigators of flight problems has had to be almost purely empirical, or, when mathematical or deductive, has been unsuccessful.

EXAMPLES FROM NATURE

Besides constituting the most conclusive evidence imaginable of the perfect practicability of flight, as well as serving as the original and a constant stimulus to man in his efforts to achieve navigation of the air, the birds and other animals that fly afford models that naturally merit the most thorough and profound consideration of all students of aerodynamics. For in nature's mechanisms of flight must exist answers to all the problems of flying, awaiting for their discovery only the analyses and applications of sufficiently persevering and painstaking investigators.

It is the easiest thing in the world to jump at conclusions, first to assume a hypothesis and then seek evidence to uphold it—which more often than not means the overlooking or the disregard of evidence that contradicts the preconceived opinion. But the real scientific method calls for investigation to learn facts rather than to prove theories—research to collect information rather than to discover arguments. And in approaching this field of research thus, with open minds, there is found little sound basis for the altogether too common reasoning that the bird wing is not a proper model for close copying by the aeroplane builder.

Bird Investigations, carefully and systematically conducted, and embracing a great variety of flying creatures, undoubtedly will afford a great deal of valuable and important data now lacking to students of the science of aeronautics. In the writer's opinion no more important work relating to aeroplane progress could be undertaken by well-equipped enthusiasts or ambitious technological institutions, than investigation, analysis, and tabulation of the weights, areas, exact forms, flying speeds, and habits of different birds.

How much remains to be done in this direction will be appreciated from the fact that the flying speeds of most of the commonest birds are not accurately known, except in such

Several methods of securing such data with regard to bird speeds suggest themselves. One is that originated by Dr. E. H. Hankin, and referred to in his "A Study of Bird Flight." Hankin's method consists simply in observation of the time required by a bird to cross the field of vision of a telescope, from which data, in combination with a knowledge of the size of the bird, the approximate distance away and the rate of movement can both be readily calculated.

Another plan, seemingly of much promise, would be simply the extension of the well-known method of training carrier pigeons. There seems no doubt but that these birds have so long been utilized for the conveyance of dispatches because of their size and their sturdy flying capabilities, as well as their susceptibility to domestication, rather than because of the possession of any uncommon homing instinct. Probably almost any birds, trained by the process of removing them repeatedly to greater and greater distances from their nests, and then releasing them, would develop the same facility of finding the way back that is possessed by the carrier pigeon. Systematic investigation of this sort, which could be readily carried on by even the most youthful and ill-equipped enthusiasts, would quickly settle many doubts and fictions as to what the speeds of different birds actually are.

PHYSICAL RESEARCH

By laboratory research with special and suitable apparatus, much has been discovered and much more remains to be discovered, concerning the laws of elastic-fluid movements.

Wind Tunnels have been extensively employed by investigators of air-current phenomena, conspicuous examples being the cases of Maxim, Montgomery, Eiffel, and others. In experiments with which the writer is familiar, and which were directed by Montgomery, the tunnels used were shallow wooden troughs, eight to ten feet long, and from two to four inches deep and eighteen to twenty-four inches wide. Provided with plate-glass covers through which observations could be conducted, these funnels were used as means of testing the different surfaces from which data was desired.

In the form that afforded the most satisfactory results, one end of the tunnel was left open while into the other a blast of air was sent by a centrifugal blower. A series of fine wire-gauze partitions in a canvas double funnel at the en

of the tunnel served to render the flow even and to break up eddies and side currents that might originate in the blower. The enlargement served to compensate for the loss of opening due to the wires of the mesh. Also, the use of the canvas between the solid wood of the funnel and the revolving masses of the blower and the electric motor employed to drive it, was found effective in damping out vibrations that otherwise might have interfered with some of the experiments.

The speeds of the air currents ranged up to forty miles an hour.

The trial sections, which when thin were bent out of sheet metal and when thick were carved out of wood, were used in two ways.



Figure 1.—Wind tunnel, used for measurement of the lift and drift of different specimen surfaces placed within it. The glass top makes it also available for observation or photography of the flow of the air streams around different objects.

If the object were simply to observe the course of the air currents the sections were made long enough to reach from the bottom of the tunnel to the glass cover, which held them



ing as a road to results presents advantages even over experimentation with full-sized machines.

In the first place there are the vastly lesser costs involved, enabling a greater variety of devices to be tried with a given expenditure, but even more important than this is the fact that a model affords a much closer check than a large machine upon the quality of the result, because its size renders it more directly and readily comparative with the results that can be shown to be secured by the birds.

Evidently, for example, in comparing a bird with a model of the same size, area, and weight, not until the model affords a similar flatness of gliding angle, as high and efficient sustention, and as low forward resistances, can man consider himself able to apply all that the bird embodies and that his present models—and presumably, therefore, his large machines—do not.

The fact that no model has yet been built that compares in any degree favorably with the birds thus construes itself into a most conclusive condemnation of the inefficiencies of present-day aeroplanes.

It might be easy to argue, of course, that a proper reason for aeroplanes differing so widely from bird forms may be that the greater size of the aeroplanes may demand some difference in conditions and construction, but this argument certainly seems untenable in the face of the showing that a similar shortcoming exists in models as compared with birds, in which case there is not the size difference to be cited as the reason for it.

In the writer's knowledge of the art, and with the exception of certain recent instances in which he has been personally concerned, no one has ever made a model in the way of an exact copy of any bird—of exactly the same size and proportions—and certainly until this is done the field of model experimentation can scarcely be considered exhausted. Indeed, it in all probability is an absolute fact that prior to the publication of this book no accurate and systematic determinations of bird's wing sections had ever been made, and the results made public.

Even with birds themselves, much interesting model experimentation might be carried on. Thus dead birds can be trussed up in different positions, and their gliding qualities determined, as well as their balance in different positions

Or the wings from dead birds may be attached to one sort and another of dummy bodies, and the different results, in innumerable combinations that will suggest themselves, tabulated and compared.

Mathematical and Geometrical Analyses are undoubtedly a most difficult but in the long run certain to prove the most valuable road to the formulation of a science of aerodynamics. Something of what has been done in the way of mathematical investigation of flight problems can be found in the work of Lilienthal, Maxim, Langley, Zahm, the Wright brothers, and in the latter portion of the next chapter. That much remains to be done almost goes without saying.

WING DESIGN

Though not always so considered, especially by the rank and file of inadequately-equipped experimenters, the absolute basis of all aeroplane flight is and always must be the wing, making the questions of wing forms and wing construction really the most important that the practical aviation engineer has to face.

In the coinage of the term "wing design," therefore, it is believed that there has been created an expression to cover concretely and adequately the very fundamentals of the flight problem.

And that a thorough knowledge of wing design, in combination with a proper conception of the action of a wing in the air, is the most important equipment an aeroplane designer can possess is a fact so evident that it can scarcely be gainsaid.



CHAPTER TWO

THE WING IN THE AIR

Since the forms and functions of wings constitute the absolute basis of flight, it follows that for a complete understanding of the laws governing this most wonderful of nature's phenomena, no investigation can delve too completely or exhaustively into the many questions concerning wing design and wing action. As summed by Professor Montgomery in the introductory paragraph of his paper referred to in the preface of this book, he declares, with a truly remarkable insight, when the time of writing is considered, that "The wing of a bird resting upon a current of air, though the ideal of simplicity, is nevertheless as worthy the deepest study as the indifferent-shaped piece of lodestone, which carries in its bosom the wonders and mysteries of electrical science. As the one performs its operation without visible movement, by mysterious power, and excites ceaseless investigation; so the former, poised in the air, develops and perpetuates a series of operations according to a code of mathematical laws, whose existence is unsuspected and whose secret workings, wonderful in the extreme, suggest further inquiry into the relations of forces."

THE SUSTAINING FUNCTION

The most fundamental function of an aeroplane wing is the sustention of the machine to which it is attached. All other considerations concerning its design are secondary to this, which has to do most directly with the means whereby a heavy and substantial structure of solid materials can be made to rest and move about so securely upon an invisible highway of elastic fluid, which in its ordinary manifestations appears so imponderable that the result secured has almost the seeming of something miraculous.

AIR PRESSURES AGAINST NORMAL SURFACES

Perhaps the readiest means of visualizing the idea that under suitable conditions the free air of the atmosphere can

become a most tangible substance, fully capable of transmitting and reacting to the most violent forces applied to it, is to cite the effects of winds. No one, who will think of the times he has had to lean heavily into the teeth of a gale, or who has had to resist being blown from the roof of a building or the deck of a vessel, will fail to remember the sensation as that of being upheld or thrust against by something almost like a solid substance. And if there be further considered the similar violence of the wind experienced in a speeding automobile or an open railway car, it at once is evident that it matters little whether the air be moved against a resisting object, or the object against the air.

Wind pressures against plane surfaces have been extensively investigated by many engineers, largely with reference to the force of their effects upon the integrity of high buildings, bridges, and the like. These investigations have led to the compilation of tables, which are commonly used by architects and engineers for the computation of wind stresses on tall and exposed structures. A table of this sort which has been long recognized as an authoritative embodiment of the data available on this subject is the following:

Miles Per Hour.	Pounds Per Square Foot.	Miles Per Hour.	Pounds Per Square Foot.
1	.005	30	4.428
2	.02	35	6.027
3	.044	40	7.872
4	.079	45	9.963
5	.123	50	12.300
10	.492	60	17.712
15	1.107	70	24.108
20	1.968	80	31.488
25	3.075	100	49.2

More recent investigators, including Prandtl, Eiffel, and other engineers of international reputation, are fairly unanimous in insisting that the foregoing table averages about two-thirds too high in its values, a good deal of careful experimenting having afforded results materially at variance with the older formula. These discrepancies may or may not be due to disregard of the "reaction impulse," discussed in a subsequent chapter of this book, but this is a point that can be settled only by further research.

Eiffel's table is as follows:

Miles Per Hour.	Pounds Per Square Foot.	Miles Per Hour.	Pounds Per Square Foot.
1	.003	40	4.800
2	.012	45	6.075
3	.027	50	7.500
4	.048	60	10.800
5	.075	70	14.700
6	.108	80	19.200
8	.192	90	24.300
10	.300	100	30.000
15	.675	110	36.300
20	1.200	120	43.200
25	1.875	130	50.700
30	2.700	140	58.800
35	3.675	150	67.500

INCLINED PLANES

Inclining a plane in an air stream—although contrary to the supposition of many, an inclined plane bears little or no real analogy in its action to that of a fully-developed wing surface—is useful to afford a basic conception from which to evolve a readily-understandable outline of the abstrusities of wing action.

To commence at once with a geometrical concept most removed from the condition of a plane placed directly across an air flow, the placing of an infinitely-thin plane in a fluid

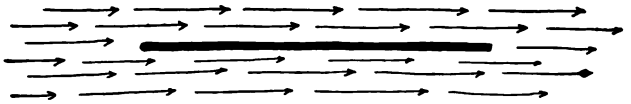


Figure 2.—Thin surface placed in a stream parallel with the flow, showing the lack of any disturbance in the fluid were there no skin friction.

stream, at no angle to the flow, as in Figure 2, can be considered to exert no effect whatever upon the flow of such fluid. Similarly, to reason from the theoretical to the actual, a plane of material exceedingly thin might be expected to exert only an almost negligible effect upon the flow of the fluid, but practically this is not quite the case, except at very low speeds, because of a factor that is easily overlooked—the friction of the fluid upon the two surfaces of the plane.

From these explanations the reader will be now able to understand why the actual effect of a thin plane, edge-on in an air stream, is something as illustrated in Figure 3. In this the air at AA is for all practical purposes inert and distinct from the flowing stream, because of its tendency to cling to the surface as a result of the skin friction.

The Visible and the Invisible Structures thus shown to xist conjointly as combined factors influencing the flow of he stream, are deserving of profound consideration, since in hem there is introduced a phenomenon extensively en- ountered throughout the science of aerodynamics, and one- t the basis of many failures to produce operative devices, ommonly ill-conceived in that a visible structure only is rovided, without proper regard for the fact that undesired nd invisible additions to the structure are certain to come nto existence when operation is attempted.

In the case in point, there is virtually an invisible structure dded to the visible structure by the banking-up of clinging and pushed-along air particles, and, though the air constitut- ing this invisible addition to the structure at any given moment is constantly moving away—in movements that may

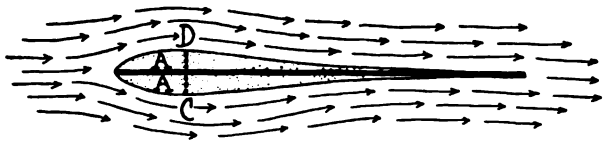


Figure 3.—Actual effect of thin surface in a stream, the air at A A being banked up by skin friction.

tend to assume wave forms of definite periodicity—it is as constantly being replaced, and its movements are so slow and so different from those of the stream proper that it is to be logically classed as an invisible element of the structure rather than an element of the stream.

The thickness of the invisible structure along the dotted line **DC**, Figure 3, will be determined by a variety of factors. It is not the writer's intention to attempt herein to tabulate them in quantitative values, but in a general way it can be said that, qualitatively, the thickness—or the addition to the projected area—is fundamentally based upon the thickness of the surface itself, factored into certain relations with the width and roughness of the surface, and with the speed of movement.

The reason for the so-called "stream-line" forms and sections now partially discloses itself, for if in place of the invisible structure of comparatively quiescent air in Figure 3, there be substituted the additional material shown in

Figure 4, the effect will be similar—the resistance being substantially that of the thin surface—with the advantage that there is now room for a strong and solid structure, if the

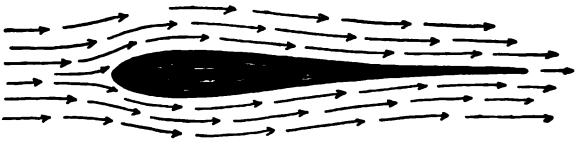


Figure 4.—Stream-line form, suggesting the thickness of material that may be provided without disturbing the air flow materially more than it is disturbed by a thin surface.

case be the one of an operative device involving the practical requirements of solidity and strength.

Recurring, for the purpose of developing in the reader's mind a correct idea of wing design and wing action, to the

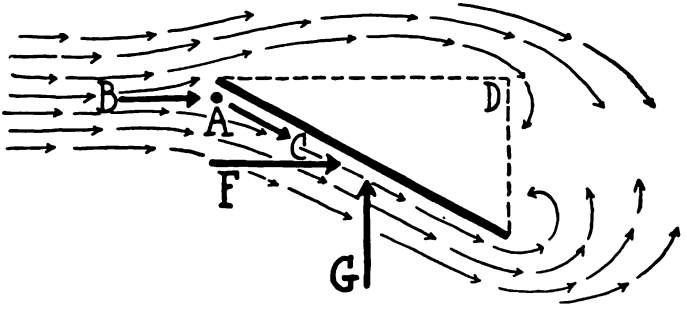


Figure 5.—Plane surface at an angle in a fluid stream, which it parts to the projected distance D. The direction of drift is shown by the arrow F, and the lift by the arrow G. An air particle A, approaching from the direction B, is compelled by the action of the surface to change its course to C.

geometrical concept of the flat surface of infinite thinness introduced into an air stream, let this surface now be considered at an angle to the air flow, as in Figure 5, instead of parallel to it as in Figure 2.

The Division of the Air Flow is the most significant element in this new arrangement, for now, no matter how extreme the thinness of the surface, the parting of the air flow of necessity involves a *measurable* separation, greater than and independent of that due to the air banked up by

skin friction and massed against the front edge. Restated in a simple, but therefore an unavoidably crude way, this is because the projected distance **D**, Figure 5, of the surface angled across the air current, is now a definite quantity that bears no necessary relation to the thickness of the surface.

The Division of the Pressure is the important resultant of the division of the air flow, the force acting to move the surface being now split into two components—one tending to *drift* it back with the flow of the fluid, in the direction of the large arrow **F**, Figure 5, and the other to *lift* it in the direction **G**, *across* the stream.

Obviously, from the standpoint of efficiency in wing design, the most desirable form is the one affording a maximum "lift" while involving a minimum "drift."

CURVED SURFACES

Could it be assumed that the action of a frictionless plane at an angle would be to direct the air streams exactly parallel to its surfaces, as in Figure 2, there would be with this sort of a surface no building up of invisible structures of quiescent air, and no separation of the air streams by more than the thickness of the surface. In this case the lift and drift figures would be the plain resultants of the simple diagonal of forces, and the thin flat surface might be used as a wing. But this conception of an analogy between a flat surface and a wing surface involves several errors of such fundamental quality that they demand only brief consideration as a preliminary to their conclusive dismissal. To begin with; any one with the most elementary mechanical information will understand that an air particle at **A**, Figure 5, which has been moving in the direction **B**, cannot abruptly change to the direction **C** upon reaching the surface of the plane, since for it to do so would require that its momentum be suppressed and its direction of movement changed in an infinitely brief time, which is absurd, since only an infinite resistance could do this. The conclusion therefore becomes imperative that an air particle deflected from its path by the action of a plane surface is deflected gradually, in a curved path, by the action of inert air massed against the plane, which air therefore constitutes the addition to the surface of an invisible structure wholly changing its nature and providing, after all, a curved surface in-

stead of the plane the casual observer might be tempted to premise, on the ground of what is to be seen.

In accord with this reasoning, with thin surfaces used as aeroplanes, analysis and experiment alike have shown a far greater effectiveness in forms something like that shown in Figure 6, in which the curve here is substantially parabolic. With such surfaces the effect is to force the divided air streams into such courses that the portion below the surface affords a maximum upward pressure while that above perhaps tends to leave the surface at certain points, further augmenting the lift by the production of a partial vacuum. At the same time, the drift component is reduced to a comparatively low figure—away below what would be due to the projected section of the whole curve.

The Angle of Incidence, AB, Figure 6, by which is measured the height of the front edge above the rear in the air stream,



Figure 6.—Air streams around a thin curved surface. Note that a rarefied space is left at C.

is very slight in the surfaces most efficient, and the top of the curve, at **C**, is very much higher than the front edge. This seemingly unfavorable form and disposition of the surface is in reality an essential element to its effectiveness, and the reason it does not have the detrimental effects the lay reasoner would be inclined to expect is because the weight sustained upon the air under the wing at **DDD** compresses it, and by the portion of this pressure that acts forward produces a most pronounced rising trend in the air current at **E**, to as much as from two to six chord lengths in advance of the surface, with the result that it approaches at a tangent to the entering edge of the surface, and is cut by it with a minimum disturbance.

This rising current in front is a most fundamental factor in the action of all wing surfaces, and failure to consider not merely its existence, but also the various conditions that may

create, modify, or suppress it, will render defective any wing design evolved without regard for them.

Wing Sections, from another standpoint than that of the curvature alone, demand close consideration. The first factor that operates in determining the proper section for a wing is that demanding a sufficient thickness towards the front to allow for a structure of the needful strength, while at the same time smoothing out all hollows that otherwise must become less properly and effectively filled with more or less quiescent air, seriously impairing the stream-line "reaction impulse," previously alluded to, and given exhaustive treatment in a subsequent chapter. This matter, the provision of the thickened section needful to allow space for a massiveness and rigidity of structure, and demanded by most

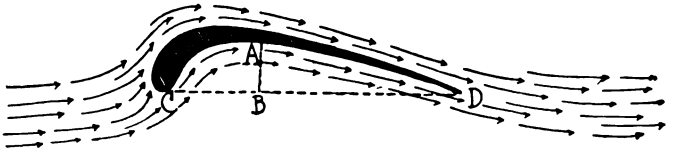


Figure 7.—Air streams around a thick curved surface.

abnormal angles, as would be the case in flight whenever upward or downward steering were attempted.

Formative Functions of certain portions of wing surfaces, as distinguished from the sustaining function, are well established to exist. Undoubtedly the reason the rear edge of a bird or other wing can be so frail without danger of breakage or loss of form is that the pressure on top at this point almost equals that beneath. This condition probably contributes, too, to the extreme forward position of the center of sustaining pressure in a proper wing.

WING OUTLINES

The reason wing surfaces must be wide across the direction of travel, and short in its direction, is sufficiently evident in the sidewise escape of the air indicated in Figure 8, and which would reach proportions hopelessly absurd in a surface like that suggested in Figure 9. In the latter case, with the surface moving in the direction indicated by the large arrow, and with the air flowing as shown by the small arrows, and with the proportions sufficiently extreme, the rear portion of the surface, at **A**, would cease to be of any value whatever for sustention—besides which it would in most machines seriously interfere with longitudinal balance and equilibrium.

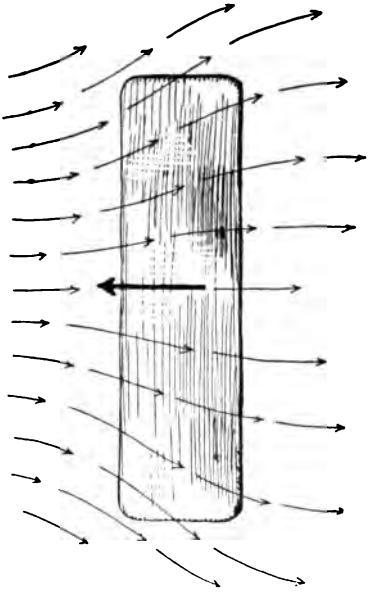


Figure 8. Lateral displacement of air flow across an aeroplane surface.

Aspect Ratio is the term given to the ratio between the span divided by the chord, and within limits that are deter

mined more by structural than by aerodynamic conditions a high aspect ratio is the best.

As crude means of minimizing the detrimental escape at the wing ends, an extreme lengthening of the wing is beneficial, since the chord dimension of the wing is a prime factor in determining the magnitude—the quantitative values—of the side flows of the air currents. Hence with a long wing a maximum ratio of effective center portion to a minimum of ineffective end portion is secured.

Another, a less crude means of improving the wing, is to taper it from tips to center, so that without an extreme span, and despite great chord depth at the center, the area affected

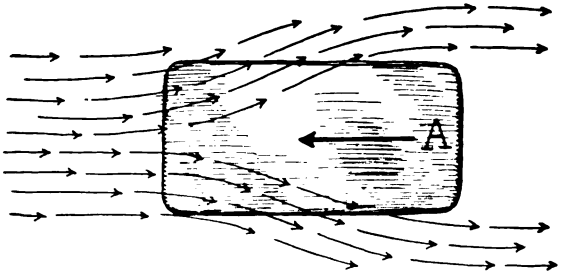


Figure 9.—Elongated surface in air stream, showing the necessity for width rather than length, as a means to utilizing the whole of the surface.

by the extremely unfavorable condition at the ends of an

sion naturally must manifest itself by reducing the rising current.

MODIFICATION OF THE WING SECTIONS

In consequence of the condition mentioned in the preceding paragraph, all that the writer has explained heretofore concerning correct wing surfaces has related only to ideal wings in front of which the conditions are assumed to be such as to develop the rising current to its fullest extent, and across which the flow of the divided stream is parallel to the direction of flow, or more accurately, of wing movement. But that these ideal conditions can be expected to prevail throughout an actual wing, permitting a uniform or nearly uniform section from tip to base, is not for a moment to be imagined, and the widely current supposition that they can has been perhaps a source of more unsatisfactory results than any other single fallacy that has found adherents in this field of engineering.

To quote Montgomery again, "Suppose the two ends be prolonged indefinitely, or what is equivalent, the plane descend between two parallel surfaces, which cut off the escape at two opposite edges; the air will then be compelled to escape equally around the two remaining edges."*

The foregoing is a terse definition of the ideal condition, but that this condition is realized or can be realized in practice is an assumption so patently wrong that complete investigation is sufficient to warrant its complete dismissal.

Again considering Figure 7, which is an exact reproduction of a section of a pelican's wing, the maximum depth of the curve, from A to B, is approximately one-sixth of the chord of the wing, from C to D, and this wing section properly used is far more efficient in every way than the shallower curves now used by aeroplane builders. Yet the writer knows of no case in the design of any prominent aeroplane (with the exception of the Montgomery gliders built in 1904, and since) in which the depth of the curve exceeds one in twelve, and one in twenty or twenty-four is more usual in up-to-date aircraft. Lilienthal experimented with curves as deep as one in eight, but despite the fact that he ascribed to these greater

*This statement deals only with the elementary condition of *surface dropping* between parallel walls, but in so far as it refers *the action at the ends*, it applies to any wing surface, either drop *or progressing* horizontally.

lifting capacity than he could secure with shallower curves, he discontinued work with them because of an assumed impossibility of utilizing them either safely or efficiently.

From the foregoing, and the similar oversights of experimenters who followed Lilienthal, there is to be deduced a lesson of the profoundest import to investigators in all lines of research. Never was there a better illustration of the folly of jumping at conclusions.

In the course of the past twenty or thirty years there probably have been several dozen men, many of them scientists of highest repute and abilities, who in the most painstaking way, and with all manner of caution to avoid error have set up apparatus to move curved surfaces through the air, or to flow air over curved surfaces, with a view to the determination of the course of the air flows and the measurement of their quantitative effects. As a result of this labor there abound, in the literature of flight, tabulations almost without end, of the comparative lifts and drifts with all kinds of surfaces at all possible angles. And yet the highest value of all this work has been largely invalidated by a simple oversight that has almost completely blocked investigation of the very deep curves that are indubitably the best and most efficient. For as investigator after investigator has progressed from flat plane to deep curve, invariably he has reached at around eight to one a tendency for the drift to increase faster than the lift as the curve is deepened, indicating here a limit that there could be nothing in trying to pass. Combine with this the disconcerting tendency of the deep curve thus tested to flip downward at low angles of incidence, from the air striking on the top of it, and the reasons for regarding it as impossible seemed quite sound.

But apparently to only one scientist in the world was it plain, as a result of mathematical and geometrical analyses rather than of experimental investigation, that the seeming fault of the deep curve was a fault wholly due to its use in the wrong place. And while others were confirming each other's observations that a very deeply curved surface gives high lift but high drift, and is dangerously unstable, Montgomery clearly understood that the total effect with a surface like that pictured in Figure 10 could be only a *compound effect*, a resultant of the most perfect action obtainable, along the center portion B, subtracted from by a heavy

down pressure *on top* of the wing ends AA, for which points the deep curve is as totally unfit as it is absolutely right for the mid-wing.

The effect of the general failure to understand this necessity for wing modification has been literally astounding. All present-day aeroplane wings are made the same in section from center to end, or practically so to the end. Flight is accomplished with such wings by ramming them through the air by wastefully powerful motors, against an invisible load that rides on top of the wing ends and thus adds itself to the visible load. Plus this is the further fault that both loads, the necessary visible load and the unnecessary invisible load, are sustained by a mid-portion of the wing that besides being

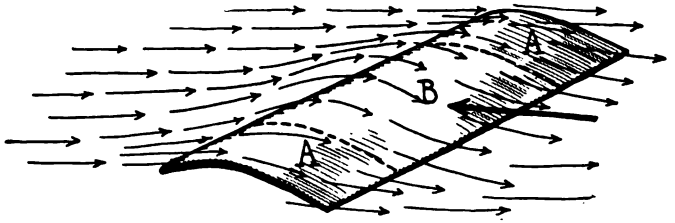


Figure 10.—Aeroplane with uniform curvature to ends, showing the air current rising over the center portion of the surface at B, but striking down upon the ends A A.

less than the full wing in area is additionally wrong and inefficient because men have assumed that that which was found wrong in one place must prove wrong in another.

On the other hand, in the domain of nature, the birds put the quality of the best aeroplanes to shame by efficiencies hundreds and even thousands of times as great. And in bird wings, with no exceptions, there is always present the modified form—a constant variation in the sections from base to tip.

It is to be emphasized, in any analysis of the reasons for modifying wing sections from the base to the tip of the wing, that in addition to the angular displacement of the air flows there is also involved a defect in the rising current that demands a *progressive* augmenting of the angle of incidence *towards the wing tip*, as well as the modification in the form *of the sections.*

Thus in wind-tunnel experiments of the character previously described, the flow of the air currents is directly across the surfaces, but with a wing in free air, with its ends not adjacent to walls, this simple and ideal straight flow of the air ceases, and two new and important conditions come into being, which if here briefly summarized may perhaps help to a more lucid exposition of the condition as a whole.

The primary of these conditions, which is most intimately related to the plan form of the wing, has been shown graphically in Figure 8. In this, the square-ended wing is moving broadside on in the direction of the large arrow, with the result that the air streams flow across it as shown by the small arrows. The point of particular interest is that it is the freedom of escape sidewise towards the ends of the surface, allowing the air to flow slantingly across the wing tips, that demands the gradually lessening angles of incidence as the center is approached, where the ideal or normal condition may prevail.

If there be a body placed at the center of the wing, as is normal in all birds and in many aeroplanes, there may be no point at which the flow of the air currents is without sidewise slant. The result is that in addition to the determination of what constitutes the proper wing sections, and their proper angles of incidence, there is the further necessity for determining the angles across the wing at which they must be placed at the given points in a given wing to insure a normal and efficient action. From the aeroplane constructor's standpoint a simpler way of viewing the matter is to regard it as a question of what forms of parallel sections in a wing are structurally necessary, as means of producing the correct non-parallel, sections at the various angles. This is illustrated in the slant section of a bird wing shown at **A**, in Figure 11.

A common means of dodging rather than dismissing the difficulty concerning modification—a means by which most serious sacrifices are commonly made solely because of ignorance of how to preserve an advantage while avoiding disadvantages—consists in the almost universal use of shallow curvatures, it having been found in the course of superficial experimenting that with wings as they are built there is serious danger of the air striking *down* on top of the wings, towards the tips, when uniformly deep curvatures are used.

ANGLES OF INCIDENCE

As has been suggested, the angles of incidence at which perfectly formed wings operate most efficiently are very much flatter than is commonly supposed. This is because the angle is considered with reference to the line of flight rather than with reference to the approaching air streams.

Naturally, to exert its lifting effect, a wing must advance at a positive angle through the air flow, but that this angle may be negative to the line of wing movement is a phenomenon that has mystified many observers not cognizant of the rising air current in front of the wing and the built-up reactions around it.

Professor Montgomery had published in 1893* the following observations on some experiments with dried bird wings:

"If a wing was placed suddenly in a wind so that the front and rear edges were in a line with the direction of the wind [with no angle of incidence], there was no sensible pressure on the under surface; but if the wing was first placed oblique to the wind [at a positive incident angle], the under surface facing it and slowly turned [tilted down] till the edges were in the position first mentioned, the air continued for some minutes to press on the under surface. Also, when this position was reached, the down on the under surface, from the front edge back to nearly one-eighth the width of the wing, continued to be ruffled, indicating a movement from this point toward the front edge.

"The first two phenomena suggest that when a plane is set obliquely to a current, a structure is given to the fluid movements, which continues to exist after the edges have been placed in line with the current."

In repetitions of this experiment with which the writer is familiar, a pronounced lift still existed with a negative angle of incidence, but if, when carefully held at the same angle the wing was suddenly moved sidewise into new air, it thrust down as though struck on top with a hammer, thus clearly proving the presence of the formed rising current in the one case and its absence in the other.

* In "The Proceedings of the International Conference on Aerial Navigation," Chicago, 1893, Pages 223 to 226, inclusive [misindexed page 323].

WING SIZES

While the proportions of wings are determined chiefly by aerodynamic considerations, the size of a wing is chiefly a matter of the load it is intended to support, and is therefore a secondary consideration in the design of the machine. However, as is suggested elsewhere herein, it is a fact to be taken into consideration in designing a machine that on large areas there is permissible a greater loading per unit of area than can be tolerated on small.

THE WINGS OF BIRDS

Believing that the wings of birds offered a field of research that had not before been properly exploited, the writer recently initiated some novel and very thorough investigations of this interesting subject. The result was most surprising, in that it confirmed a previously-entertained but nevertheless rather uncertain opinion to the effect that no accurate determination and publication of bird-wing sections has heretofore been made.

Doubtless the new results secured, and herein made public for the first time, differ so widely from previous work directed to the same object largely because of the superior method employed in the present instance.

This method, which proved most effective for the purpose, was to take the wing from the freshly-killed bird and fasten it in a wooden box, into which melted paraffine was immediately poured. Then when the paraffine had hardened, the whole mass—box, paraffine, wing, and all—was easily cut into regularly-spaced sections with an ordinary handsaw. In this way there was obtained the most perfect and accurate data that it seems possible to secure, in the way of exact information concerning the real form of birds' wings. This will be very apparent from the photographic reproduction of one of the sections, used as the frontispiece to this book, and the traced reproductions of the wing sections and plans of six large birds, in Figures 11, 12, 13, 14, 15, and 16.

It is of course to be understood that a bird's wing may, and probably does undergo minor changes in form when it is carrying the weight of the bird in the air, but the extent of such changes cannot in any case be very great, and presumably *is quite slight*. This is because a bird's wing is for the *most part very strong* and stiff, while the flexibility of its



weakest portion, the rear edge, undoubtedly is offset in large measure by pressure acting on the back of the wing in flight, in such manner as to counteract much of the pressure beneath the rear wing edge. The fact that there does exist such a pressure must, moreover, largely discount the deductions of Lilienthal and others as to wing deformability, when it is considered that their tests were made by loading inverted wings with sand and the like, with no consideration of the fact that there might under normal conditions exist a pressure counteracting a part of the load.

As a result of thorough investigation, it is most informing to summarize the chief points in which the bird-wing form differs from the usual aeroplane-wing form.

These points of difference are two in number. First is the gradual modification from base to tip, and second is the presence of an enormously-thick and deeply-downturned front edge.

The reasons commonly advanced against the propriety of following nature in the aeroplane wing are likewise two in number. First it is argued that the thickness of the front edge is a necessity to provide for the thick bones of the wing, which lack the reinforcement of wire bracing with which the wing bars in an aeroplane can be provided, while the second supposition is that the modification and the depth of curve are involved by the flapping rather than by the gliding function of the wing—it being, of course, a fact that even the most highly-specialized soaring birds must on occasion be capable of flight by flapping. But it is also a fact that the most-highly specialized flapping birds are in many cases good gliders. Moreover, there is every reason for supposing that even steady flapping, or "rowing flight," as it has been aptly termed, involves a gliding action of the wing—either simultaneous or intermittent with the forward-and-back propelling movements.

Thus careful analysis suggests that the common arguments are somewhat specious, but experimental investigation seems to go further than this, and prove them absolutely unfounded.

In formulating the laws of flight, it is well to note that throughout all of the wonderful perfection of nature there is nothing more evident or impressive than the perfect interre*lation of all laws* and all structures. And, if the thick fro*edge is demanded* in the bird's wing by virtue of a structu

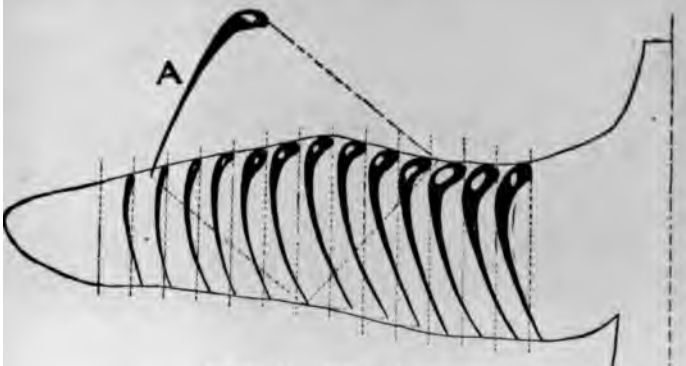


Figure 11.—Wing of pelican.

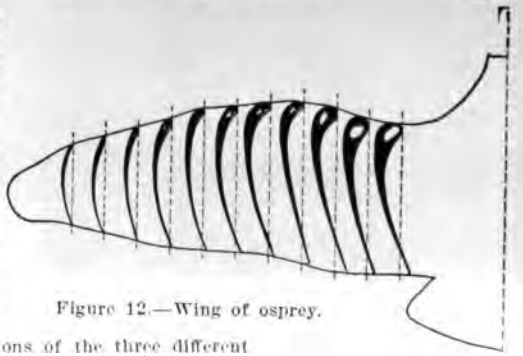


Figure 12.—Wing of osprey.

These plan and sectional illustrations of bird-wing forms are believed to be absolutely the first of their kind ever published, and in any case are of a character and accuracy to present startling contrasts with accepted ideas of what aeroplane wings should be. It is to be noted that, despite the close similarity in the wing sections of the three different birds shown on this page, they include distinctly different types of flight, the pelican being an excellent glider and the duck almost exclusively a flapping flyer. The wing section reproduced photographically in the frontispiece herein is the fifth from the base in the pelican's wing shown above.

The maximum thickness of birds' wings ranges from one-sixth to one-tenth of the chord, and is always located very close to the front edge, rarely farther back than one-tenth of the chord distance. The center of the sustaining pressure is similarly far forward, so that the wing balances almost on the bones that support it.

As is clearly shown in these illustrations, the flattening towards the tips is very pronounced in all birds' wings, and when the plan of the wing does not taper off to a single point it tapers to a plurality of points.

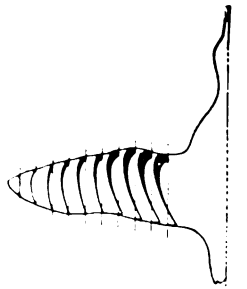


Figure 13.— Wing of duck.

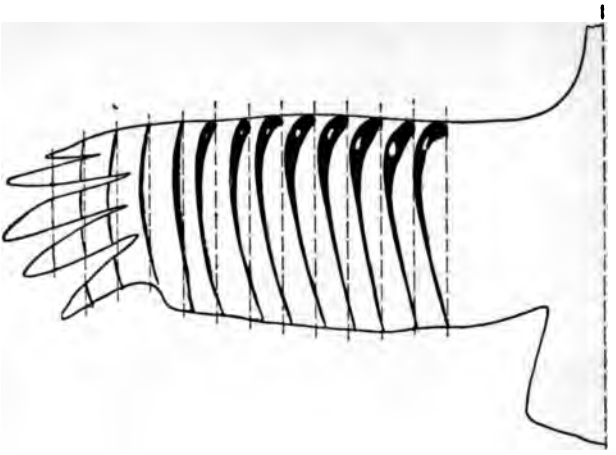


Figure 14.—Wing of turkey buzzard.

The wings on this page are from birds all noted for their soaring capabilities, despite which the wing of the gull rather closely resembles that of the duck. The weights sustained per unit of area on the wings of these different birds are: duck, 3.00 pounds; pelican, 1.50 pounds; osprey, 0.89 pounds; buzzard, 0.80 pounds; hawk, 0.76 pounds; gull, 0.75 pounds.

One law that becomes obvious from a study of these wing sections is the thickening and increase in the dip of the front edge with increase in the loading. This condition appears to be universal, with no exceptions.

Because of the substantial similarity of the wing sections in both soaring and flapping birds, it is impossible to believe that the section is materially specialized to meet these conditions. What seems more reasonable is that flapping is less dissimilar than it appears from gliding and soaring flight, and that the rowing movement of the wing does not at all relieve it from or interfere with the more fundamental function of serving as a gliding surface, as well during its extreme dihedral and drooped positions as when horizontal. The fact that all soaring and gliding birds can, upon occasion, perform flapping flight, seems further to confirm this view.

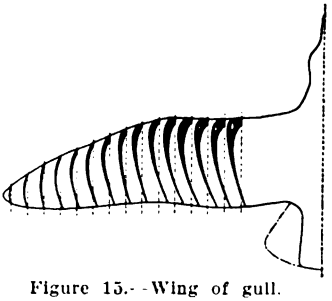


Figure 15.—Wing of gull.

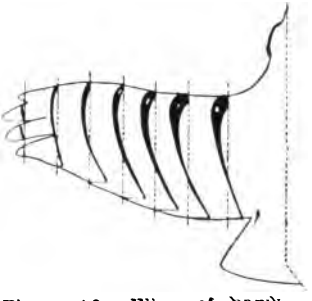


Figure 16.—Wing of hawk.

necessity, this is no reason whatever for supposing that it is not equally required by aerodynamic conditions. Indeed there is more reason, as there is more evidence, for supposing it to be required to meet an aerodynamic need, than there is for supposing it to be demanded merely to accommodate a structural necessity.

Moreover, were the latter the controlling factor, it is reasonable to suppose that the wing thickness would be merely sufficient to contain the bones and necessary muscles, when as a matter of fact the thickness is much greater than this in the wings of all birds the writer has examined

becomes thicker, more deeply curved, and more abruptly downturned.

In the same paper referred to in the footnote on Page 14, Professor Montgomery has the following to say concerning the curvature of birds' wings:

"In the examination of the wings of hawks, buzzards, eagles, sea gulls, pelicans, wild geese, and other birds, I found the under surface of the wing from the front to the rear edge a true parabola, varying in its curvature, both according to the relation between the weight of the bird and its wing surface, and the proportion of the length and breadth of the wing. A comparison between these various models suggests that the curvature is also affected by the tilt given the wings from the base to the tip.

"The parabolic curvature a few inches from the base of the wing seems most perfect. At this point the front edge is the vertex of the parabola.

"In comparing the distance between the front and rear edges—the chord—with the focal length of the parabolic curve, the following order seems to exist. The length of the chord is to the focal length as the weight of the bird is to the wing surface; this relation being affected by the proportion between the length and breadth and the tilt of the wings. I do not give this as an exact proportion, but simply as an indication of the relations. In the pelican's wing the chord is five or six times the focal length of the curve; in the gull's it is three or four times, while in hawks and buzzards it is two or three times.

"The difference between the focal length and the chord decreases in passing from the base to the tip of the wing—i. e., the curves become more open; and from the center to the tip the front edge gradually varies from the principal vertex of the (parabolic) curve."

ANALYSIS OF WING ACTION

Again to refer to Professor Montgomery, the following, which was written in 1893, and has been since partially republished in different periodicals at various times, is probably the briefest and most concise analysis yet made of certain important aerodynamic phenomena and their relations to wing form and action.

This paper will well repay the most studied and critical

reading, with close reference to the illustrations whenever they are cited in explanation of the text.

"In determining the proper form of surface, the first suggestions are derived from the conception of a body projected in a straight line but deflected from its course by a constant force acting at right angles—as a mass projected horizontally and pulled down by gravity, thus describing a semi-parabola, according to well known laws.

"In Figure 17, let AB represent the direction and distance a mass M, projected horizontally, would pass in two instants of time, AE and EB representing equal times. But under the action of gravity, the mass will describe the curve AHD. Drop the perpendicular EH to the curve; then the point H

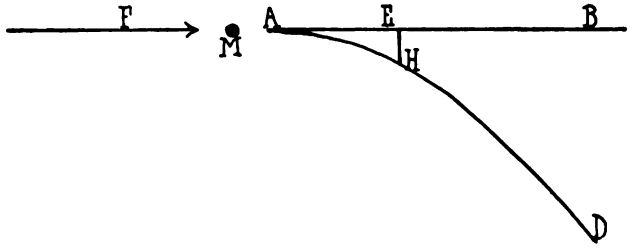


Figure 17.—Path of a mass simultaneously acted upon by gravity and a horizontal force.

as shown in Figure 18. In this AB is the directrix, LM the tangent, and C the focus. In the evolution of the parabola, FG = CG, KH = CH, etc. Subtracting the distance AL, between the directrix and the tangent, from FG, KH, etc., and the radii of the circle from CG, CH, etc., the differences are equal; that is, the perpendicular distances from the circle are equal to those from the tangent. A further study of this development shows that all these lines FG, CG, etc., form equal angles with the tangents to the curve at the points of inter-

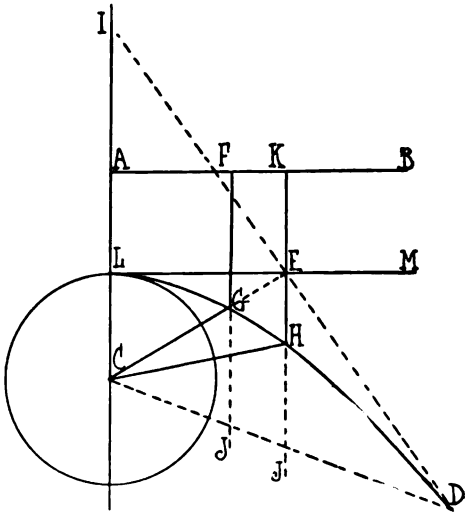


Figure 18.—Relations of the elements of the semi-parabola to the action of a wing.

section. From these two considerations we see that equal impulses from the tangent LM and the circumference of the circle will meet at the curve, producing resultants in the direction of the tangents at these points. And finally, according to a well known property of the curve, all impulses from the center will be reflected from a parabolic surface in parallel lines (as JJ), and, vice versa, all parallel impulses (as JJ) reaching the surface will be reflected to the focus C.

"Before making application of these properties, I must call attention to a phenomenon of jets or streams. If two jet

impinge on one another, as shown at **A** and **B**, Figure 19, the particles will escape at the point of impact in lateral movements **CC**. If the streams are equal, the point of impact will remain fixed; but if they are not, it will be driven towards the weaker jet.

"The application of these various elements is shown in Figure 20, in which **AHD** is a parabolic surface placed in a

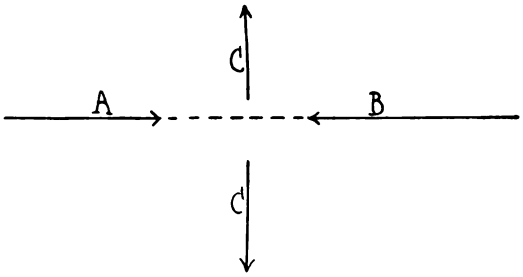


Figure 19.—The phenomenon of impinging jets.

fluid and **S** is a jet fixed in the line **AB**. When an impulse from this jet impinges on the surface it will develop pres-

arrow F. And, further, as it moves along the curve, meeting the reaction of the fluid as shown at O, it produces the phenomena shown in Figure 19. And as the direction of impact is parallel with the tangent at this point, one element of the resulting lateral pressure is against and normal to the curve; while the opposite element is towards the fluid mass, and in the direction the normal MN. But an analysis of the normal shows it is composed of two equal elements, one, MC, pointing to the center C, and the other, MJ, perpendicular to the line AB. As this impact of the stream and reaction of the disturbed fluid takes place along the entire surface, producing a normal pressure at every point, there is a diversity of pressures in the fluid mass, which diversity is harmonized by the analysis given; all the elements represented by MC going to the center C to build up a center of pressure, while the elements represented by MJ develop parallel pressures against the fluid. These pressures being parallel with those represented by F combine with the latter to produce a compound effect—first, they impart to the adjacent mass the movements PPP, and this movement sets up a rotation around the center C; and, second, the reaction of the disturbed mass against the impulses F and J is transmitted as an impulse back to the surface, and is reflected to the center C, thus increasing the compression at this point. As might be surmised, the reflected impulses to the center C would have a tendency to drive it out of position, but the impulse S (as an element building up this rotation), is an opposing force, keeping it in place. Owing to the concentration of the various lines of force and the restraining influences, and because of the rotation, the point C becomes a center of pressure from which there are constant radiating impulses, which reaching the curve are reflected from its surface in lines parallel with the first impulses. But, as a radiating center sends out equal impulses in equal angles, there is a new distribution of pressure on the curve because of these radiated impulses. An inspection of Figure 18 will show that the angle ICE = ECD. Hence, the impulses falling on LG equal those falling on GD. The point G then becomes the center of pressure on the curve due to the radiated impulses from C, while H is that due to the parallel impulses *from the first* reactions, F, Figure 20, of the moving particl *against the* curve. But between the points G and H th

should be another central point of pressures due to the elements MN. The reason for this will appear in the following consideration. Suppose we have a number of elastic particles in a straight line, and a constant force acts on the first; each particle successively will react against the force, thereby building up a gradually increasing pressure, till the last is set in motion. And owing to these successive increments of reaction against the force, the pressure will be least at the last particle, gradually increasing in an arithmetical progression to the first. From this it would appear, that the elements MN should increase in intensity from D

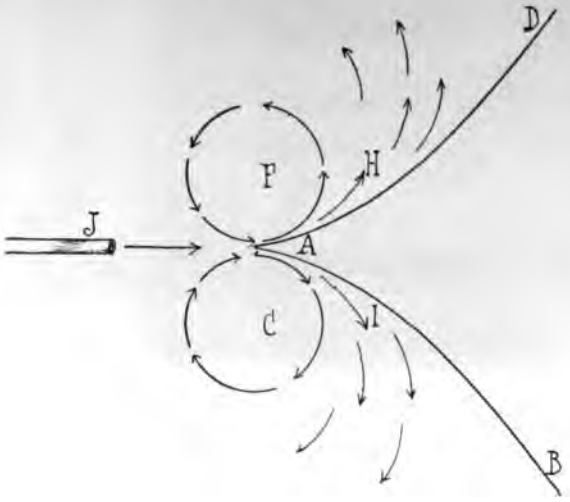


Figure 21.—Balance of two symmetrically-placed semi-parabolas.

is cut off by the length of the wings), the intensity should be proportional to the width.

"In an experiment illustrated in Figure 21 some of the phenomena mentioned are shown. In this AB and AD are two surfaces, corresponding to AHD, Figure 20, placed in shallow water,* and J is a jet of air near and parallel with the surface. The jet sets up a stream on the surface, which is cut by the point A and flows along the curves as shown at H and I. In flowing along, these streams, H and I, set up movements, as shown by the small arrows, which pass into rota-

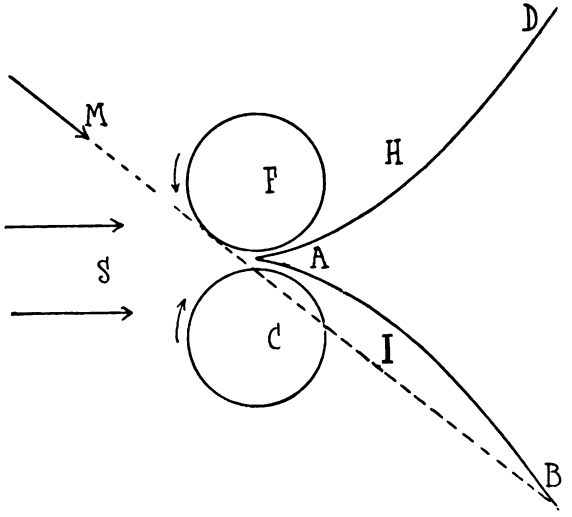


Figure 22.—The proper angle of a single semi-parabola in a fluid stream.

tions around the points CF. Particles of chaff on the surface reveal these movements, while pins fixed at the foci of the parabolic curves, and extending above the surface, assist in observation.

"If the planes shown in the last experiment are placed in a stream S, Figure 22, the same development of pressures takes place, but the complete rotations are hidden because

*Fluid movements are qualitatively about the same in water as in air, though quantitatively vastly different.



of the general movement, though they substantially exist in a general wave line. In this system, there are three general elements of action and reaction; first and second are H and I, which mutually hold one another in balance, and act reciprocally in building up and maintaining the various movements and pressures; and the third, these combined reacting on the exterior stream. Should one of the elements H, for instance, be removed by taking away the curve AD, the development would be destroyed and there would be an escape from I towards the side H. And in order to re-establish the pressures on the curve AB there must be a readjustment by which the necessary element is derived from the stream. An inspection of the figures shows that the rotary tendencies around F press upon those of C and also on the rear of the curve AB. Then if we draw a tangent of this circle F to the point B, and so place the curve that the stream comes from the point M, we find the desired adjustment, though the pressures on the curve are derived from modifications of the ideal movements.

"On placing the curve AB so that the stream approaches in the direction MB, Figure 23, we test the adjustment as follows: Fine sand scattered at A on the bottom, by its movements will indicate that the approaching stream is cut by the point or edge A. But if this point be lowered, there will be a pressure on the upper surface, causing a whirl F. Whereas if it be elevated a reverse whirl, C, is produced, as shown in the illustration.

"In the complete system of movements in this adjustment

"In the rear the various movements combine and form a displaced current, traveling parallel with the original stream. Owing to the pressure exerted by the descending current on the upper rear surface, the effectiveness of that on the under surface is reduced. * * *

"If we take a curved surface narrow enough to be sub-

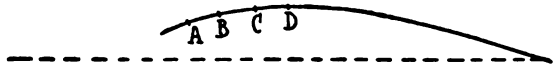


Figure 24.—Modification necessary in wing section towards the tip of the wing.

merged, part of the fluid will escape over the upper edge, and the reactions necessary to produce the rising current in advance of the plane are only partially developed. Hence to have the front edge cut the current, it must be elevated. This required elevation of the front edge increases as the surface is more completely submerged, as the escape of the water over the upper edge is thereby increased. But if portions of the front edge, as shown at **ABCD**, etc., Figure 24, be cut off, to allow for the deficiency in the rising current, the front edge of the curve may be lowered so that the remaining portion of the curve may assume its proper position. The application of this is readily apparent in the wings of a soaring bird. Towards the center, near the body, the curvature is at its fullest development. But near the outer extremities, where the air partially escapes around the ends, the sharp front curvature disappears, the wing surface becoming less curved and more narrow—a fact that has been noted by many investigators.

"Here I must call attention to an important element. In discussing Figures 18, 19, and 20, I pointed out the positions of the centers of pressures, and in Figure 25 we find the application. Let **EB** be the horizontal, and also the direction of movement of the curve **AB**, in its proper position. From the construction, we see that the center of pressures due to the direct reaction of the moving particles is at **F** while that due to the pressure emanating from the center **C** is at **G**. If we draw a normal from the point **F**, its inclination is against the direction of motion, **EB**. But one drawn from **G** inclines with it, or forward. The resultant of these two pressures is indicated by **H**, and the normal to the tangent at the

point shows a slight forward pressure. From the study of Figure 20 we find that there is a third element of pressure, MN, whose intensity is greatest towards the front. This again changes the location of the center of pressure, placing it in advance of the point H. And as the normal at this point inclines forward, there should be a perceptible forward pressure developed, a phenomenon I have observed when testing my aeroplanes, and one which I believe has been observed by others.*

"These conclusions regarding the location of the center of pressure seem to be confirmed by observations made when

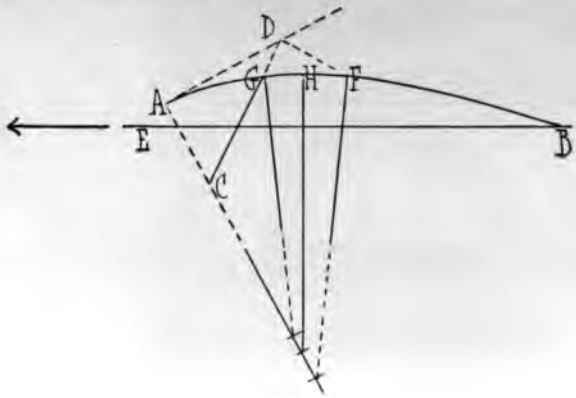


Figure 25.—The factors that determine the center of pressure and its forward inclination—the "Tangential."

I first entered this study. Taking specimens of large birds, eagles, pelicans, buzzards, etc., newly killed, I braced their wings in the normal position of soaring. I then balanced the body by thrusting sharp points into it, immediately under the wings (frequent corrections having been made to adjust the bracing so as not to introduce errors into balancing), and I found the center of gravity under a point in the wing approximately corresponding with the point I have indicated as being the center of pressure.

"Before leaving this part of the subject I must call attention to two important elements—first, from a study of Figure

* *This is the so-called "tangential" noted by Lilienthal, and confirmed by the Wrights and others.—(Author.)*



23 it is seen that it is the reaction within or under the curve that causes the ascending current in advance of the curve; hence, should there be an object within this space, causing a resistance to the fluid movement, it by reaction will further increase this rising current, and as this is increased the front edge may be lowered still more, and thereby the element of pressure on the forward surface augmented, which will partially compensate for the resistance due to the object; second, in the use of two surfaces, one in advance of the other, the line of development is suggested in Figure 23. Suppose this surface be divided at D and the sections moved apart, the intervening space gives to each part an individuality, but their mutual reactions give them an interrelation. Hence in the practical use of such surfaces the curvature of that forward should be more pronounced, and its inclination greater than that in the rear. However, without a proper understanding how to determine these elements dangerous mistakes might be made."

THE FORWARD RESISTANCES

The resistance aeroplane wings—and the other elements of the structure—oppose to movement through the air are the measure of the power required to maintain it in operation In the case of a wing the accepted term to describe these resistances is "drift."

AERODYNAMIC DRIFT

In its original sense, as employed by Chanute, who coined this use of the word, drift was understood to mean only what for the sake of more accurate distinction the writer prefers to characterize as the "aerodynamic drift"—the backward-acting element of the pressures against a wing surface. See Page 85.

There are, however, two other ways in which a flow of air may tend to drift an object along with it, and this condition has led to confusion not so much by complicating analysis as does observation of a given condition.

FRICTIONAL DRIFT

This is the type of drift due to the grip of the air by skin friction on the wing and other surfaces



HEAD RESISTANCE

The direct pressure of the air against the edges of wings, and of all other elements involved in an aeroplane, in accordance with the accepted tables of wind pressure (See Page 42) is commonly considered as part of the resistance that must be battled against by propeller thrust. And as a matter of fact this is the case in improper designs, but with the use of stream-line forms a different condition is introduced, for which reason the writer has substituted for "head resistance" the term "penetration drift", as is explained in detail in the following chapter.



CHAPTER THREE

THE ENERGY REQUIREMENT

Absolutely the most backward and the least developed department of aeronautical engineering is that relating to the energy required to move a flying machine through the air. First deterred altogether from even a hope of a satisfactory result by the seemingly insuperable difficulties in this branch of the problem, when competent engineers did seriously undertake its solution they were then misled, by the development of the light-weight gasoline motors that had become available with the advent of the automobile, into clumsy evasions of the finer flight problems—resulting in the use of devices having for their basis the most brutally inefficient elements made operative solely by their employment in conjunction with the grossest excesses of squandered power.

This misapplied energy has been expended chiefly in the form of wastefully-excessive propeller thrusts, necessary to overcome head resistances that in modern aeroplanes are unnecessarily present, and therefore are mistakenly allowed for in computations that have been loosely based upon the various approved wind tables.

As far as the mere "aerodynamic drift" (see Page 71) is concerned this—by means that are still so inefficient and incorrect as to admit of much further improvement—has been reduced in at least a few fast modern machines to so small a proportion as one-twentieth of the lift, requiring for the purpose of overcoming it, for example, only fifty pounds propeller thrust to fly a thousand-pound machine.

In the matter of skin friction, this at most does not exceed fifteen or twenty pounds in an average aeroplane, at the usual speeds of operation.

Consequently it is impossible to find any adequate explanation, other than that of excessive head resistance, to account for the three-hundred and four-hundred pound thrusts necessary to fly present aeroplanes. And as this is out of all *proportion* to the results secured in nature's flying devic



: appears evident upon the face of it that something is rrong.

To discover the reason for this discrepancy between results secured and results that apparently should be secured. he writer has recently devoted considerable time to an investigation of this neglected subject.

The result of his work has been the discovery of a herefore overlooked aerodynamic phenomenon of the utmost importance in its relations to the energy requirement, and vhich, by proper application of its principles, is beyond question destined to contribute the essential basis to a new era of aeroplane progress.

RECOVERY OF THE WORK OF PENETRATION

It has long been known, as a result of observation and experiment, that objects of certain shapes offer less resistance than others of the same projected areas to rapid movement through air and water, or other fluids. But despite this general knowledge, extending even to a widespread understanding of the forms that afford the most advantageous effect, not the slightest glimmering of the real reason for the advantages secured seems to have entered the minds of even the most clever and resourceful investigators. For this reason no intelligent application of these forms has been possible, and even the attempt to apply them has been widely neglected.

STREAM-LINE FORMS

The type of body that offers a minimum resistance to movement through a fluid is that having a stream-line form of the general outline shown in Figure 4.

The Prevalence in Nature of the stream-line form is alone sufficiently conclusive evidence of its superiority for its purpose. Though modified in innumerable minor respects to meet special or individual conditions, its essential and fundamental characteristics appear in the bodies of practically every creature that moves at any but the lowest speeds through air or water.

In the water, from the smallest fish to the largest whale, there is always the characteristic type of outline—in front either bluntly rounded or with the greatest thickness in *any case well forward* of the middle, in combination with



a more finely tapered rear body sloping back in reverse curves to a pointed or thin-edged tail.

In the air, the bodies of all birds present similar contours, and, as with the denizens of the deep, there is the same notable principle from which there are no deviations. For, no matter what variations there may be in the heads of the different creatures, which present the greatest and most complex dissimilarity, there is never any material modification of the apparently fundamental necessity of placing the greatest thickness forward of the center, with the after portion of the body always provided with the finely-tapered stream outline.

Nor are nature's applications of the stream-line principle by any means restricted to body-like elements. The fins of fishes, and particularly the flippers of seals and the flukes of whales, as well as the wings of birds—as is abundantly shown elsewhere herein—invariably disclose upon careful measurement or dissection characteristic stream-line sections.

Analyses of Experiments of the different investigators of this subject are most informing, and, indeed, were the means by which the writer reached his original conclusions, which were not until sometime subsequently checked against and confirmed by his own practical tests and experiments.

In a research of this character, it is a policy always worthy of consideration, to regard the data of preceding investigators as more deserving of consideration than are their conclusions, the first being matters of fact and the second matters of opinion. A consistent regard for this policy in the attitude maintained towards the work of others will enable the discriminating worker to avoid retraversing much old ground in efforts to determine the physical facts underlying observed effects.

This being the case, the writer will employ for the illustration and proof of his explanations widely-accepted data derived from the work of others, commencing with the experiments of Hiram S. Maxim in 1894.

Maxim's experiments were conducted to determine the resistances of different forms of struts, and the lift and drift of different forms of sustaining surfaces, which he contemplated using in his famous Baldwyn Park aeroplane, and which for the purposes of the test were placed across the mouth of a wind tunnel having an opening three feet square.

The air blast was supplied by a revolving fan, working be

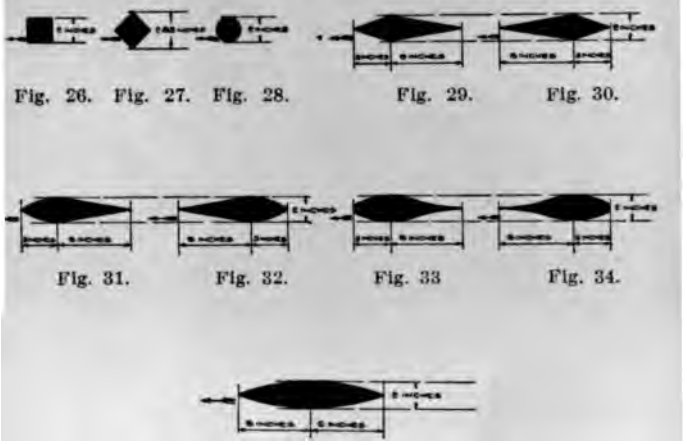


Fig. 26. Fig. 27. Fig. 28. Fig. 29. Fig. 30.

Fig. 31. Fig. 32. Fig. 33 Fig. 34.

Figure 35.—Strut forms used in the Maxim experiments.

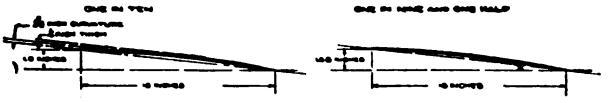


Figure 36.

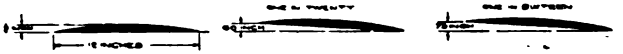


Figure 37.

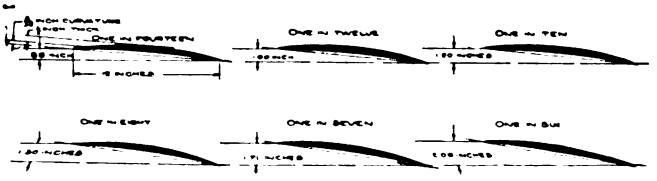
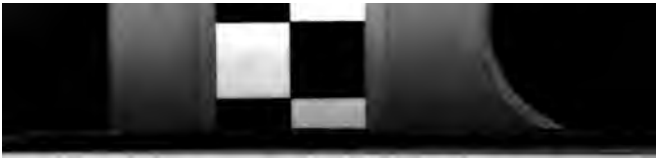


Figure 38.
Sustaining surfaces used in the Maxim experiments.



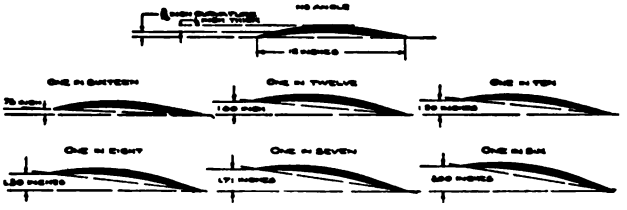


Figure 39.

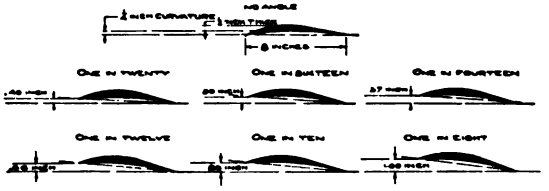


Figure 40.

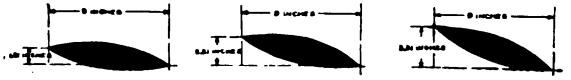


Figure 41.

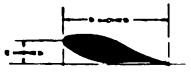


Figure 42.

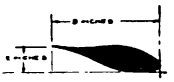


Figure 43.

Sustaining surfaces used in the Maxim experiments.

ind a plurality of internal partitions that prevented eddies n the current at the point where it reached the pieces under est.

All of the surfaces tested were long enough to reach be- ond the edges of the tunnel entrance, so that a portion of ach surface exactly thirty-six inches in length was subjected o the conditions.

Commencing with the ten different struts illustrated in Figures 26, 27, 28, 29, 30, 31, 32, 33, 34, and 35, it is to be noted hat the thickness or projected section of all of these is ex- ctly two inches, with the single exception of that in Figure 7, which is the same as that of Figure 26, turned so that it stands cornerwise instead of flatwise to the air current. It also is to be noted that Figures 29 and 30, 31 and 32, and 33 and 34 are alike, simply reversed in direction.

For the purpose of ready comparison, the results secured with these ten different sections are tabulated on the opposite page.

The next experiments were with the five different aeroplane sections illustrated in Figures 36, 37, 38, 39, and 40, and with the surfaces shown in Figures 41, 42, and 43, of which it is to be noted that the two latter are the struts shown in Figures 33 and 34, used as sustaining surfaces.

In the tabulation of the effects secured with these different surfaces, there are a few points that seem at first most paradoxical, but which subsequently reveal themselves as possessed of the most astonishing significances.

To call attention to these briefly: first it is to be noted that though the projected area in Figure 27 is increased by 41½ percent over the projected area of Figure 26, the pressure acting against it is increased by only six percent.

Second is the observation that in the cases of a 22½ percent increase in the speed of the air currents applied to the struts in Figures 26 and 28, the pressure acting against the square bar increased over thirteen percent, while that against the round bar increased only six percent—less than half as much. Had the increase been with the square of the speed, as is commonly assumed, the pressure against both bars should have risen 48.8 percent.

Most extraordinary, of course, is the fact that the greatly-*elongated sections* illustrated in Figures 29 to 35, inclusive, *show such a remarkable* lowering of the resistances below

FIG. NO.	LENGTH (In.)	WIDTH (In.)	ANGLE	PROJECTED THICKNESS (In.)	AREA (Sq. In.)	DRIFT (Pounds)	LIFT (Pounds)	DRIFT (Per Sq. Ft. of Projected Area)	LIFT (Per Sq. Ft. of Projected Area)	EFFICIENCY RATIO
..	6	6.00		...	36.00	2		8	...	
26	36	2.00		2.00	72.00	5.16		10.32	...	
26	"	2.00		2.00	72.00	4.56		9.12	...	
27	"	2.83		2.83	101.88	5.47		7.69	...	
28	"	2.00		2.00	72.00	2.97		5.94	...	
28	"	2.00		2.00	72.00	2.80		5.60	...	
29	36	9.00		2.00	72.00	.78		1.56	...	
30	"	"		2.00	72.00	1.22		2.44	...	
31	"	"		2.00	72.00	.28		.56	...	
32	"	"		2.00	72.00	.42		.84	...	
33	"	"		2.00	72.00	.23		.46	...	
34	"	"		2.00	72.00	.59		1.18	...	
35	"	12.00		2.00	72.00	.19		.38	...	
36	36	16.00	1 in 10	1.60	57.60	1.12	9.94	2.80	2.48	8.87
"	"	"	1 in 9½	1.68	60.48	1.23	10.34	2.90	2.58	8.40
37	36	12.00	None.	.50	18.00	...			...	
"	"	"	1 in 20	.96	34.56	.30	3.98	1.25	1.33	13.26
"	"	"	1in 16	1.12	40.32	.53	4.59	1.83	1.53	8.66
38	36	12.00	1 in 14	1.28	46.08	.44	5.28	1.37	1.76	12.00
"	"	"	1 in 12	1.40	50.40	.50	5.82	1.43	1.94	11.64

those secured with Figures 26 and 28, which present the same projected area.

In the cases of the sustaining surfaces, it is to be noted that though the lift progressively increases with increase of angle, the drift increases at a much faster rate, so that with the surfaces used in the tests, which in their best examples are similar to those used in modern aeroplanes, the most efficient lift-to-drift ratios are found at the flatter angles, with less than the maximum sustentions.

Even more interesting is the fact that in the gradual progress from thin to thick surfaces shown in Figures 37 to 40, inclusive, there is a progressive decrease in the drift resistance as the thickness becomes greater.

Perhaps the most extraordinary result of all is that secured with the strut illustrated in Figure 33, when used as a sustaining surface in the two positions illustrated in Figures 42 and 43, the superior effect secured with the blunt edge foremost being particularly a contradiction of preconceived opinions. And a comparison of its dimensions and the lift and drift figures it affords, with the similar figures secured from the sections illustrated in Figures 37, 38, and 40 will further confound the preconceived opinions.

Little less astonishing are the figures derived from the strut shown in Figure 41.

A remarkable feature throughout all of the tests is the much lower drift resistances secured with the elongated strut sections than are secured with the still more elongated sustaining surfaces, which though placed at slight angles, are at angles that in most cases still afford far less projected area than is present in the strut sections.

To reconcile or to dismiss the seeming inconsistencies between these different results, which were accurately checked by Maxim, and which can be easily confirmed by any one, seemed to the writer a problem worthy of the most profound investigation, though it has proved most abstruse and baffling to a great number of experimenters who have been wont to assume, probably correctly, that the actual head resistance of an object moved through the air is determined more by its projected area than by the form of its front or rear portions.

To the extent that this opinion concerns the front portion, *it probably is in* large measure correct, for if the form be *other than that* best adapted to penetrate the air with a

minimum resistance, inert air massed against it will automatically assume such a form and thus in large measure supply the lack. This has been clearly evident in many wind-tunnel experiments, in which the front form of an object has been found not to change greatly the resistances.

The same thing has been repeatedly observed in automobile races at extremely high speed, cars with pointed fronts not being materially faster than those with square fronts. Yet that there is some difference due to changes in the front is shown in the Maxim experiments by the difference in the resistances of the struts illustrated in Figures 29, 30, and 31, as compared with that illustrated in Figure 35.

A common hypothesis to account for the greater resistances of struts shown in Figures 26, 27, and 28, as compared with those shown in Figures 29 to 35, inclusive, is premised upon the supposition that the air in some manner banks up against the front or eddies around the edges of these blunt forms in such a manner that the width of the disturbed track in the air is much greater than the projected section of the object. But reference to the frontispiece of this book will show that this conclusion must be now dismissed, since wind-tunnel experiments, accompanied by methods of rendering photographically visible the disturbance and separation of the air streams flowing around solid objects immersed in them, prove the direct contrary, it being now known that the separation of the parted air currents is not materially greater in the case of shapes that are proved to possess high resistances than they are in the cases of properly-formed stream-line bodies.

The consequence is that some other explanation than that of greatly differing head resistances would seem to be necessary to account for the extraordinary superiority of stream-line forms, and to reconcile such apparently conflicting data as that from the Maxim experiments.

THE REACTION IMPULSE

And this explanation, by scientific analysis and deduction, as well as by processes of experimental elimination and demonstration, can be proved to exist only in a heretofore unsuspected effect exerted on the rearward portion of a stream-line *form—and lacking* in the cases of other forms—whereby th *elements of* the parted body of air spring together ag

fter they have passed the point of maximum separation, *nd thus nullify the head resistance almost completely by a lefinite propelling pressure exerted against the tapering rear of he body as it escapes from between the wedged-apart masses f the surrounding atmosphere*—for all the world like a vatermelon seed projected from between the moistened ingers of a small boy, with this difference, however, that in he case of the air the friction is so low, the air so perfectly lastic, and the pressure so advantageously applied, that under avorable conditions the action is probably one of the most fficient known in engineering—undoubtedly well over 99 percent in the case of the birds. In the case of the section shown in Figure 35, with a resistance of .19 pounds, if the section shown in Figure 26 be accepted as a standard of normal pressure, with its resistance of 4.56 pounds pressure, then the change to the elongated section eliminates over 95 percent of the pressure. Actually, since the strut in Figure 26 presumably benefits in some degree from the reaction impulse, the efficiency as compared with an accurate standard of normal pressure must be still higher. The effect of this condition in its relation to the power demand will be realized upon reference to the final paragraph under propeller "Thrust," on Page 139.

Indeed, this action is found by experiment to be so extraordinarily efficient that it certainly renders totally unnecessary and definitely wrong the use of very thin wing surfaces and similar elements in aeroplane design, now that it can be shown that the reduction of head resistance is of only the slightest importance, as compared with that of utilizing the wonderful means available for recovering almost the whole of the energy expended in overcoming it. For example, comparing the effects secured from the strut shown in Figure 26 with that from Figure 35, the latter of which possesses only one-twenty-fourth as much resistance, and taking this into consideration in conjunction with the fact that the total projected area of an average aeroplane is only from 20 to 35 square feet, it becomes at once evident that even a single square foot without reaction recovery may easily require as much energy to force it through the air as is required for all the rest of the machine, made into proper *stream-line forms*.

This beautifully simple, though heretofore profoundly

obscure and unrecognized example of the marvelous interrelation of aerodynamic laws, as they act to "recover the work of penetration," is illustrated in Figure 44, in which, after the parting of the air streams by the stream-line form to a maximum separation of the projected distance **AB** there follows the closing together under pressure from the adjacent masses of the atmosphere, which is indicated by short arrows at **CC.**

The Factors of Efficiency in this "reaction impulse" concern chiefly the angle and the skin friction.

Obviously, as in the case of all surfaces, there is some angle so flat that the coefficient of friction will prevent the wedge from being thrust out from between the opposed pressures. With air this angle is possibly flatter than with

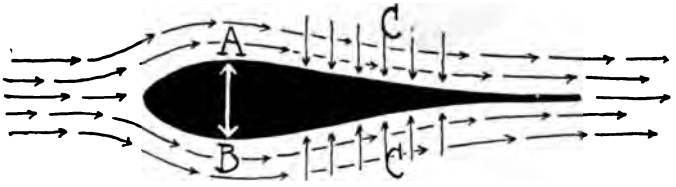


Figure 44.—Stream-line form moving through a fluid. The energy expended in the parting of the fluid streams to the projected distance A B is in large measure recovered by the reaction pressures C C, which wedge the rear portion of the form out from between the adjacent masses of fluid.

to a recovery, in the form of a reaction impulse, of some of the energy expended, is evident in the results secured in increasing the velocity of the air flow against the struts shown in Figures 26 and 28, in which case the pressure failed to increase with the square of the speed, as remarked on Page 78. From this case the writer assumes that even the inert air pocketed behind an object not of stream-line form is in greater or less degree capable of transmitting the reaction impulse. This is further suggested by the figures Maxim secured with a plate six inches square, which he subjected to the same currents to which he exposed the struts and sustaining surfaces, and the data from which is included on Page 79. But that even a slight wedge form given to the rear of a body at once renders it vastly more efficient for penetration of the air is shown by the strut in Figure 27, in the case of which, as is explained on Page 78, the increase in resistance is only one-seventh of the increase in projected area



SKIN FRICTION

Many investigators laying claim to authority in this field of engineering have regarded the skin friction of flowing air over the surfaces of solids as too slight to be worthy of consideration.

How erroneous this opinion is is conclusively evident in several familiar phenomena, once they are regarded in the light of their relationships to the subject under consideration.

A baseball, for example, which the arm of the strongest pitcher is capable of spinning only at a fairly moderate speed, is nevertheless made to take a pronouncedly curved path as the result of the difference in skin friction between the side that revolves with the direction of travel and that which revolves against it, and no baseball enthusiast needs to be reminded of the great difference in the effect produced when part of the surface has its character changed by moisture, as in the case of the spitball of certain famous pitchers.

Another familiar example of the friction of moving air upon a surface is presented in the ruffling of water areas into waves by the flow of even the lightest winds across them.

In the writer's knowledge, similarly impressive evidence in the form of specific and tabulated data has been secured by impinging jets of air against revolving balls, suspended by light threads so as to turn very freely.

Skin friction, besides being affected by the character of the surface, augments with the square of the speed, and possibly at some higher rate at very high speeds, which if so will account for its seeming a much more pronounced factor at high speeds than at low. This is especially manifest in the results secured with air propellers, which at high speeds waste so much power from this cause that it is a principal reason for their being vastly less efficient than slow-speed propellers with higher pitch.

THE AERODYNAMIC CONDITION

Having shown that head resistance can be almost entirely suppressed, and that the resistances due to skin friction are *in any case* not of great magnitude, it becomes interesting *to consider* the one other loophole for the leakage of ene

-or for the improvement of aeroplane efficiencies by stop-ing the leak.

THE TANGENTIAL

It is a remarkable fact, which has been proved by more han one experimented, that with a proper wing surface ıot only is the aerodynamic drift (see Page 71) completely uppressed, but its place is taken by a marked forward nclination of the lift component, so that instead of adding :o the forward resistances this phenomenon may be counted ıpon partially to neutralize the penetration and frictional lrifts in very perfect surfaces operating under ideal con-ditions.

Something of this sort is doubtless a partial explanation of the effortless flight of soaring birds, in which there is presumably the lowest possible reduction of skin friction by the smoothness of the feathers, a similar minimization

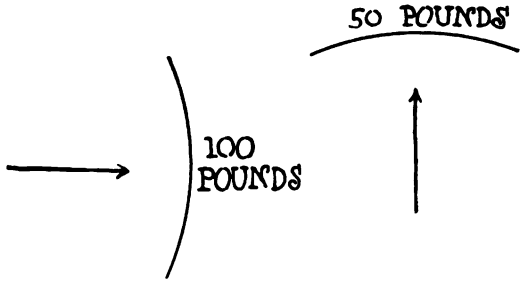


Figure 45.—Lilienthal result with curved surface placed normal to and then horizontal in a wind. In the latter case, with the chord of the curve at no angle of incidence, the lift was equal to 52% of the normal pressure.

of the penetration drift by the use of stream-line sections of forms affording the utmost efficiency in the reaction impulse at normal speeds of movement, and a maximum development of the tangential.

Second only to suppression of the drift component is the enormous increase in the lift component with a proper wing surface, the lift of which may rise to a very high percentage of the pressure against the same surface with the same air *flow, with the* chord of the curve at right angles with the *stream.*

Even as early as in 1895 Lilienthal procured the quantita-



tive result illustrated in Figure 45. That similar results are not secured in modern aeroplanes is sufficiently established by the fact that the most accurate wind pressure tables of recent years afford at corresponding speeds figures much more than twice as high as the highest sustentions yet secured with aeroplane surfaces.

For a concrete example, at a speed of eighty miles an hour, the pressure on a square foot of surface normal to the wind is certainly not less than twenty-five pounds. On this basis the Lilienthal result of fifty-two percent would call for a sustention of thirteen pounds to the square foot—over double what is realized in any modern machine of practical qualities traveling at this speed. This comparison, moreover, is even more of a reflection on the modern aeroplane when it is considered that the sustaining surface with which Lilienthal made his experiments was a thin circular arc distinctly inferior to the thicker parabolic arcs now used.

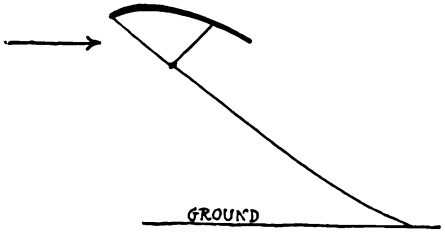


Figure 46.—Kite with proper wing curve drawn into the wind that sustains it.

GENERAL CONSIDERATIONS

The general type of wing section illustrated in Figure 7, which has been exhaustively experimented with in wind tunnels by the writer and associates, which is approximated in the best present machines, and which is the form utilized by nature (see Figures 11 to 16, inclusive), affords under proper test results that are at once most astonishing and beautiful illustrations of the marvelous manner in which nature interrelates the structurally needful in wings with the inviolable laws of aerodynamics.

As has been previously suggested, in a surface of this *form, besides* the minimization of frictional and penetrati *drift there is* the entire suppression of the drift compor

of the acting force, which therefore is discovered to be not a phenomenon of proper wing action but a phenomenon confined to incorrectly formed surfaces that it is attempted to utilize as wings.

In this connection there are to be remembered not only the experiments of Lilienthal, in the course of which he discovered the tangential effect just explained, but also the observation of Chanute in 1896, that under certain conditions a bird wing held in the hand in a sixty-mile gale was drawn strongly into the wind. It is a curious related fact that kites of certain types can be built so that they will rise vertically overhead and approach the wind as in Figure 46.

While all of the backward impelling forces perhaps cannot be eliminated from the different elements of an aeroplane, however much they may be reduced by improving the reaction impulse, reducing the skin friction, and by developing the tangential in the place of aerodynamic drift, there can remain no question but that in present machines they constitute far higher resistances than they are going to constitute in the flying vehicle of the future, which as the months speed by looms more and more upon the horizon of human endeavor as the greatest marvel of engineering perfection and efficiency that the genius of man has ever hoped to wrest from the inscrutable mysteries of force and matter.



CHAPTER FOUR

EQUILIBRIUM AND CONTROL

The equilibrium and the control of an aeroplane are two factors that sustain close and confusing relationships.

To attempt, however, a distinction that has been almost as sadly lacking in the design of the aeroplanes themselves as in the literature of the art, it may be suggested that the term "equilibrium" might advantageously be restricted in its application to such qualities in the form and arrangement of surfaces as tend by the contribution of an inherent stability to keep a machine right side up despite disturbances in the atmosphere, and independent of manipulation by the operator, while "control" and "balancing" could be properly confined to the movement of rudder and other surfaces by the operator, primarily and properly for the purpose of steering, but upon occasion and in some machines for the purpose of maintaining the balance.

AUTOMATIC EQUILIBRIUM

In its common significance this term has come to be descriptive of means or devices for correcting an aeroplane's deviations from its normal level automatically—independent of the attention of the operator—by the movement of controlling surfaces actuated by air pressure, electrical devices, the gyroscope, or what not.

To the writer it seems that "automatic-balancing device" is properly the term for such mechanisms—which in the majority of projects for their application are designed to effect only the lateral control, though there are exceptions.

Altogether preferable to any conceivable type of automatic-balancing device must be such disposal of stabilizing and sustaining surfaces as will produce an inherent equilibrium —an equilibrium like that of the parachute, which is almost incapable of being upset, and which if it is upset will without *attention from* the operator right itself. By this it is n*o* *meant to imply* that the only way or even the proper w



)f securing such inherent equilibrium is to place the weight ow, thus securing the pendulum-like effect of a parachute,)ut the point is that, by whatever means, an aeroplane ihould take care of the operator rather than the operator)f the aeroplane, if any such safety as is anticipated is)ver to be secured.

It can be proved by experiment with dead birds that a)ird with its wings fixed in a certain position can not fall ibruptly, no matter in what position it may be released n the air, but will always come down at a very flat and herefore safe gliding angle. And since as much has been done with at least one aeroplane, why should not this quality in machines be developed in preference to the development of complicated and therefore unreliable and **dangerous balancing devices, which amount practically to evasions rather than solutions of the problem, leaving it incumbent upon the operator to keep the machine right side up—a policy certainly inherently dangerous in that for many reasons there is always danger of momentary lapse of an operator's attention?**

STABILITY

An aeroplane can tip over either sidewise or endwise. Consequently, to maintain it right side up can require provision only for maintaining lateral and longitudinal equilibrium.

LONGITUDINAL EQUILIBRIUM

It is now well established, both from observation of flying animals and in the construction and operation of flying machines, that there are a considerable number of ways, all more or less effective, of maintaining the longitudinal balance of an aeroplane. These methods are, moreover, capable of use both independently and in various combinations.

And as has been made clear, there is further choice available in that some of these methods are of a nature to operate automatically against disturbing forces, whereas others require actuation by manual or automatic controlling means, in consequence of which they are either dangerously *objectionable*, or are more properly to be considered as *steering means*.

Separated Surfaces, two in number, one preceding the

other, constitute a most perfect means of maintaining fore-and-aft balance. Over thirty years ago it was demonstrated by Penaud in France that with curved advancing and following surfaces, the first with a positive angle of incidence and the second with a slight negative angle of incidence to the line of travel, longitudinal balance could be secured automatically in an aeroplane model. An analysis of this effect shows that in case of a dive, the speed being thereby increased, and the action of the air beneath the forward surface thus continuing a vigorous lifting effect, it tends to rise, while the air striking on the upper side of the rear surface tends to bring it down into its proper position. On the other hand, in case the front of the machine rises unduly the rear surface comes into such a position that it presents

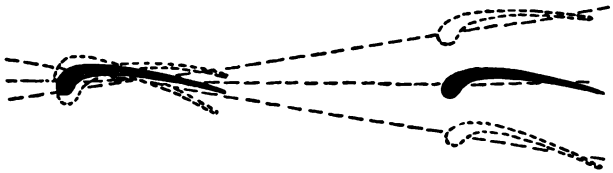


Figure 47.—Longitudinal stabilizing action of two tandem surfaces, with the second at a slight negative angle to that in front. If the front of the machine rises, the relative increase in the angle of the rear surface is greater than that in the front surface, with the result that the rear lifts and corrects the level of the machine. Conversely, if the machine dives, the angles become such that the loss of sustention is greater with the rear surface than with the front, causing the equilibrium to be promptly regained.

a much greater angle of incidence to the line of movement and therefore commences to lift in greater degree than before, thus quickly returning it to its proper level. A more detailed analysis of these stabilizing conditions is presented in Figure 47.

Obviously, to avoid exaggeration of the stabilizing effect to the point where it would disturb rather than preserve equilibrium, the two surfaces must differ in their angles very slightly.

It cannot be escaped that the convenient and effective means of longitudinal balancing, by separated surfaces, may most advantageously combine two purposes—primarily preventing the forward or backward upsetting of the vehicle *but secondarily* providing means for steering up or dow *Thus considered*, and if as is too often the case there



substituted for the safer automatic longitudinal stability a controlled longitudinal balance, the problem becomes one that admits of a variety of solutions. Thus, the elevator, or horizontal rudder surface, may be placed either at the rear or in front—the latter a placing that is more common to biplanes than it is to monoplanes, though there is a commendable tendency on the part of the most advanced engineers to discard it in both types of aeroplanes. This is because rear rudders, while affording the same steering effect as can be had with front rudders, also afford the automatic longitudinal equilibrium just explained.

Among the incidental merits due to two or more surfaces, one preceding another, is the compacting of the sustaining areas in a minimum space, so it is not strange to find that **plural carrying surfaces are commonly provided in the design of modern aeroplanes.**

LATERAL EQUILIBRIUM

True lateral equilibrium with an aeroplane can be secured in a number of ways, in addition to which there are the lateral balancing devices, consideration of which is reserved to the section devoted to "Horizontal Steering" (see Page 94), under which heading these systems more properly fall.

**Dihedral Angles at the junctures of wing pairs, as in the Antoinette and other monoplanes, possess the merit of affording considerable inherent stability in calm air, but in disturbed air they often tend to have just the opposite effect, the low position of the maximum weight causing the invariable trouble that results in thus placing it—a pendulum-like oscillation of amplitude that tends to increase until the vehicle overturns. Birds often soar and maneuver with their wings in the dihedral position, but their ability instantly to adopt other positions when occasion demands relieves them from the dangers that are introduced when the angle is made permanent. This is not to say, however, that an aeroplane with dihedral wings cannot be made to fly in a wind with considerable safety, since some machines so built have performed excellently in anything but calm weather. But the point is that the dihedral angle is not *in itself a contributing* element to stability in rough weather, *and it is despite* it rather than because of it that certain



machines are kept stable, usually through the constant manipulation of wing-warping devices.

Many soaring birds that in flight set their wings at drooped or flat angles are observed to hold the extreme tips of their wings pronouncedly upturned—possibly for the balancing effect of the dihedral position, although this is by no means certain.

The manner in which the dihedral angle operates to maintain balance is very simple. The wings being in their normal positions at angles of less than their maximum effectiveness for sustention, when the vehicle is tilted the lower wing becomes more and the higher wing less effective, so that the tendency to tilt automatically corrects itself, bringing the whole apparatus back on an even keel.

Vertical Surfaces for maintaining the lateral balance of an aeroplane are analogous to the similar use of such surfaces in box kites, and act in a most effective and wholly automatic manner—the least inclination at once bringing the side of the normally-neutral vertical surface that is toward the inclination, into play as a more or less effective lifting surface—varying with the extent of the tilting—with the result that the air pressures instantly tend to force it back to its normal position. Whether for this purpose, or as vanes or rudders, surfaces placed vertically, though not present in any flying animals except the varieties of flying fish, are found quite indispensable in man-made flyers.

Placed to the rear of an aeroplane, a vertical surface of suitable form and size will exert an especially effective and important stabilizing function by keeping the machine headed always on a desired course, or in the event of disturbing influences will head it into gusts of wind, which if continued in coming from the side might prove dangerous.

So employed, the action of a vertical surface is literally analogous to that of a weather vane, since it keeps the rear of the machine always rearmost in its line of travel. Thus if a wind gust strikes the side of a machine, broadside on, it will exert its greatest effect against the vertical surface, which if placed at the rear must immediately pivot around the center of mass and cause the machine to face the gust—a condition of perfect safety as long as the longitudinal *equilibrium is* equally well maintained by the means upo *which it is* dependent.

In the one other circumstance in which a machine can upset —if it tips sidewise and so commences to fall sidewise—the action of the vertical surface is similar to its action in the case of the wind gust, the front of the machine falling freely while the movement of the rear is impeded by the air acting against the fin, thus allowing the machine no option but to plunge head first, again a condition not dangerous so long as the longitudinal equilibrium and control means are serving their purposes.

The use of large vertical surfaces forward is now found in few aeroplanes, and is probably altogether mistaken design since its tendency is to turn the front of the machine away from the wind or its direction of fall, a condition that cannot be otherwise than dangerous.

STEERING

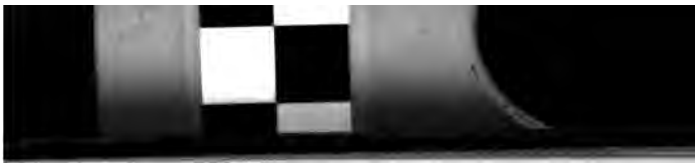
The steering of modern aeroplanes is a problem presenting so few difficulties that it has been more or less successfully solved in a very considerable variety of constructions, all of which, however, are subject to effects and conditions that must be individually studied and reckoned with by the experimenter or the designer who seeks the highest quality of practical result.

HORIZONTAL STEERING

Horizontal steering, to one side or the other without necessarily involving any change in height, is most commonly accomplished in modern aeroplanes by vertical rudders, acting alone or in conjunction with unsymmetrical manipulation of portions of the wing surfaces.

Vertical Rudders, placed generally at the extreme rear of an aeroplane, steer sidewise in almost exactly the same manner as a boat is steered sidewise by a similar rudder.

Wing Warping as a means of steering or balancing consists of a simple unsymmetrical twisting of the wing tips, so that the one on one side of the machine is tilted up, while the one on the other side is simultaneously tilted down—by any suitable means that can be used to produce this change in form. The effect is to shift the maximum lift of the wings *to one side of* the machine or the other, as a simple result *of varying the angles* of incidence—the angles of wing-tip



Properly employed, this manipulation constitutes a most important and effective means of lateral steering, but its function has been widely confused with its other possible function of lateral balancing, through its use in many machines, ancient and modern, for this purpose. In the Wright biplanes there is claimed a patented combination of wing warping with simultaneous manipulation of the vertical rudder at the rear, to resist the drag set up by the warped end of the wing, but that exactly the same effect can be secured with a vertical surface at the rear having no sidewise movement, and therefore constituting a fin instead of a rudder, is not generally appreciated. Yet use of a surface of this character, made very large to eliminate the necessity of the higher effectiveness per unit of area that can be obtained with a steered surface, quickly demonstrates its effectiveness as a rudder substitute, as well as for the stabilizing function exerted by it. This combined use is the subject of an important claim in the Montgomery patent.

In the Wright machine, or in any machine of similar type, when traveling straight ahead there is necessary frequent though usually slight manipulation of the wing warping to prevent the machine from careening sidewise. In steering, however, there is given the definite unsymmetrical twist to the wings by the warping, which causes the machine to veer in one direction or the other, while at the same time there is set up a drag that momentarily tends to produce a reverse turning movement. This movement is resisted by manipulation of the vertical rudder.

In a machine of the Montgomery type, in straight flight the lateral equilibrium is left absolutely to take care of itself, any disturbance being instantly neutralized in the manner previously explained, by the weather-vane effect of the large fin at the rear. This effect is not necessarily without disturbance of the line of travel of the machine, but if it takes it out of its course, as is more likely than not to be the case, the wing warping is then manipulated solely as a means of steering it back. In doing this, it acts simply to produce a sidewise unbalance of the machine in the direction of the turn it is desired to make. This tilt at once automatically occasions the sidewise sliding movement of the forepart of the machine, the fin resisting it at the rear. So while the wing warping thus becor

a perfect means of steering the machine in any desired lateral direction, it evidently is no more than this, being distinctly employed as an unbalancing rather than as a balancing means. In this connection it is a fact worthy of note that during Montgomery's 1904-1905 experiments his machines were safely and repeatedly sent aloft, in the presence of thousands of people, with the wing warping lashed and soldered in a fixed position, so the operator could not manipulate it.

VERTICAL STEERING

Vertical steering of an aeroplane is understood to mean steering up and down, rather than sidewise, and is effected by the use of horizontal rudders or elevators.

Horizontal Rudders, though a term that is confusingly

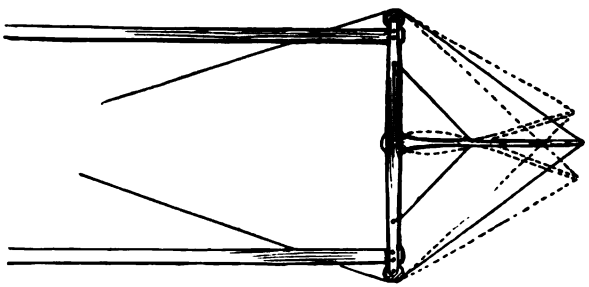


Figure 48.—Wright flexible elevator.

applied at present to the different types of surfaces, sometimes in front of and sometimes at the rear of an aeroplane, which are variously used to steer it up and down as well as to maintain its longitudinal balance, could with advantage be restricted to surfaces that are non-lifting—the type most commonly used in modern aeroplanes.

Elevators—to confine the term to lifting surfaces—while serving substantially the same steering function as horizontal rudders, are much more effective in producing inherent longitudinal stability. This is because of their secondary function as sustaining surfaces, the action being as explained *in Figure 47.*

In the Wright biplanes the vertical steering is by surfaces *made definitely to* operate against the air above as well as

below, by a scheme of flexing instead of pivoting, illustrated in Figure 48, by means of which either the top or bottom side can be given a concave curve.

The proportion of the weight carried on the elevator is rarely in proportion to the relation of its area to that of the main surfaces, because a smaller surface will not, except at excessive angles of incidence, carry as great a loading per unit of area as will the larger surface. See Page 103.

Extreme examples of the use of plural sustaining surfaces in the same plane appear in the various double monoplanes, such as the Langley and the Montgomery machines of early types, in which the two main sustaining surfaces, though equal in area, can be variably inclined to each other for the purpose of adjusting longitudinal equilibrium.

BANKING AND BALANCING

Because of the attempts to maintain that the Wright patents cover broadly all means of warping wings for any

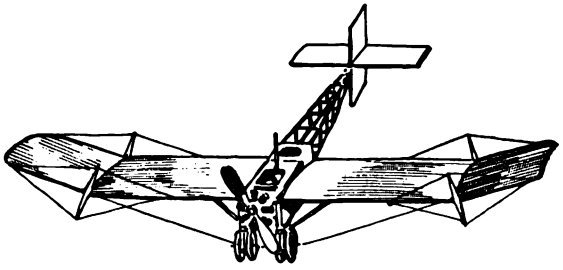


Figure 49.—Tilting wing tips, of the type employed by Maxim in 1894. These are a practicable, though not the most effective, means for steering and maintaining lateral balance.

purpose whatever, there has been a tendency to evade the letter of the Wright construction by devices for producing similar effects, presumably without infringement upon the Wright construction or patent claims.

A substantial equivalent of wing warping is the use of twin ailerons, hinged to the rear tips of the wings in such a manner that as one is moved up the other is moved down. This is a very old construction, and was applied in the early *Montgomery glider* illustrated in Figure 11, and in the machin *patented in the* United States by Mouillard in 1897.

Other designers, seeking to avoid even the appearance of the Wright construction, have used small separated ailerons, having no actual connection with the wings. Such ailerons are commonly placed midway between the two surfaces of the modern biplanes in which they are employed.

Tilting wing tips, capable of being dihedrally thrown up or down into positions more or less effective than the normal, constitute a means of balancing that was tried by Maxim in 1893. Such a system is illustrated in Figure 49.

Another means of effecting lateral balance or steering, and a very old idea, is the rocking wing, pivoted at its point of attachment to the body of the machine. Such a scheme, with the wings capable of similar or dissimilar manipulation, was used in the early Montgomery glider illustrated in Figures VII, VIII, and IX, but the idea is much older than this application of it.

Wing tips feathered out into a plurality of separated surfaces, simulating the construction that is existent in the finger-like surfaces of the wings of many soaring birds, have not to the writer's knowledge been employed in any aeroplane. The exact utility and manipulation of this type of wing tip is a mystery that still awaits satisfactory explanation, and one that perhaps contains the secret of some most advantageous means of balancing or steering.

Another feature of bird wings that offers possibilities of application to aeroplanes is the swinging wing tip, probably first used by Octave Chanute in the construction he patented in the United States in 1897, and then threw open to the public. In the form preferred by Chanute as a result of his experiments, the wing tips were held in their normal position by springs, their movement being effected automatically by variations in the wind pressure.

The relation of the swinging wing tip to the principle of variable wing area, and therefore to variable speed, is most interesting, and may well repay profound study and serious investigation of its exact effects.



CHAPTER FIVE

THE DESIGN OF THE MACHINE

In the design of aerial vehicles an exact science is becoming rapidly established, with its recognized engineering practices as well as the possible freakish departures therefrom that are found to exist in all departments of technical endeavor. For the benefit of the intending designer or experimenter, however, an important point to emphasize at the present time is that, except for those willing to copy constructions originated by others, this field of engineering is one in which nothing less than the broadest and most practical engineering knowledge can suffice to insure reasonable safety and to produce results of real importance.

Were successful aerial vehicles to have been produced by the rule-of-thumb methods that have been more or less advantageously employed in most other fields of mechanical engineering, successful flying or at any rate gliding machines would have been invented two thousand years ago, for failure in the past has been due not to lack of efforts or facilities, but absolutely to the inadequate technical equipment possessed by experimenters.

SIZE

By far the most essential points to be observed in aeroplane building are the provision of the correct wing curvatures and the proper proportioning, arrangement, and control of the different sustaining, stabilizing, and balancing surfaces —with due attention, of course, to structural strength and security. The latter, however, may be quite safely left to anyone possessed of a high grade of mechanical ability to carry out largely in accord with individual ideas and facilities, which with the exercise of reasonable judgment are as likely to prove practical and satisfactory in one case as in another.

While the space in which aeroplanes are operated imposes no serious limitations upon the size of flying vehicles, there *are other conditions* relating to this point that require to b

most strictly regarded. Possibly the quickest understanding of the situation may be most readily gained by considering the matter of both the smallest and largest aeroplanes that can find practical use.

Certainly the smallest aeroplane that can have any real value will be the one barely large enough to carry one individual, in turn involving the highest practicable sustentation per unit of area and the lowest possible weight in addition to the necessary weight of the operator.

In the other direction, though there seems less severe limitation in the way of the largest aeroplane that can be built, this is a merely casual impression that does not persist when the factors of the problem are analyzed.

THE GEOMETRICAL CONSIDERATIONS

The size of flying animals is perhaps a first source of information. The heaviest of all soaring flyers is the California vulture, similar to but in its largest specimens larger than the largest specimens of the Andean condor, and not uncommonly weighing twenty pounds and over. Occasionally certain varieties of albatross are found in weights ranging up to eighteen pounds, while turkeys are said sometimes to weigh twice this, but the latter cases presumably have reference to exceptional examples of domesticated birds, in which artificial selection probably operates to subordinate flight ability to other and more interesting requirements.

Still heavier than any present birds may have been the extinct pterodactyl, with some twenty-foot span, but which it is more than probable, however, weighed no more than thirty pounds.

In any case, no flying creature that ever existed appears to have been as heavy as the combination of a man with the lightest structure that can be made to support him in the air, and this fact often has been cited as an argument against the possibiilty of human flight, having been advanced as conclusive by no less an authority than the late Simon Newcomb. This famous scientist even committed himself to the statement, made a few years ago, that "I consider the demonstration that no possible combination of known substances, known forms of machines, and known forms of force, can be united in a practicable machine by which men can fly long distances in the air, as complete as it is

possible for the demonstration of any physical fact to be." To this he added, "Let us discover a substance a hundred times as strong as steel, and with that some form of force hitherto unsuspected, which will enable us to utilize this strength, or let us discover some way of reversing the law of gravitation, so that matter may be repelled from the earth instead of being attracted to it, and then, and not until then, we may have a flying machine." Concluding this most caustic and skeptical opinion, he said "There is every reason to believe that mere ingenious advances of our present means and forms of force will be as vain in the future as they have been in the past."

Professor Newcomb's opinion was founded chiefly upon the geometrical law that the areas of all objects increase with the squares while their bulks increase with the cubes of their linear dimensions.

The Disproportionate Increase in Weight due to this cause is simply explained by reference to Figure 50, in which the cube **A** is one foot square while the cube **B** is two feet square. With these dimensions the area of each side of **A** is one square foot, which multiplied by the six sides affords a total area of six square feet. With **B** the area of each side is four square feet, which multiplied by the six sides totals twenty-four square feet. In the matter of the contents, which determine the weight, the volume of **A** is one cubic foot, while the volume of **B** is eight cubic feet.

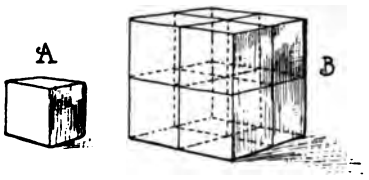


Figure 50.—Cubes showing the geometrical relationships between linear dimensions, the areas, and the bulk, and weights, of all solid objects.

From this it is to be noted that the increase of weight is much greater, even in proportion, than the increase in area, a law that applies as absolutely to all irregular and other forms as it does to the simple cube.

The effects of this law are several. In the first place it is to be noted that each square foot of the cube **A**, on the side *of the cube* that rests on a surface, has to sustain the *weight due to only* one cubic foot of mass. But in the case *of the cube* **B** the weight sustained by each square foot

hat due to two cubic feet of volume, a condition that must ıltimately place a limit upon the size to which the cube ;an be built, as the quantity of material piled up finally)ecomes greater in weight than its crushing strength per ınit of area.

This condition, universal in its application, places a limit, lespite certain compensating factors, upon the size to which ıeroplanes can be built of the structural materials that are ıvailable.

Indeed, were it not for the fact that mankind possesses ıtructural materials vastly stronger than the bones and muscles of birds, it is extremely probable that we should not be able to build flying machines larger than birds.

It is this law of the squaring of areas with the cubing of bulks that in the reverse direction operates so advantageously that an insect can fall a hundred times its height with no injury whatever, whereas larger animals are killed by falls proportionately much less.

An ant, for example, in falling from a table top, strikes upon each unit of its area with a weight equal only to the thickness above that area, whereas a man falling the same distance strikes upon any given area with the impact of an amount of material equivalent to a thickness hundreds of times as great as that of the ant.

The Gain in Unit Sustention is another geometrical phenomenon, which in a measure offsets the decrease in area to a given weight. This point, so favorable in its bearings on the problems of human flight, and as yet little understood by many aeroplane designers, is not wholly due to any single cause, though probably the main factor is the escape of air around the edges of wing surfaces—such edges being always longest in proportion to the area in the smallest sizes of surfaces. For the geometrical axiom is that the length or boundary of any given figure increases in direct ratio with any increase in the linear dimension, whereas the area increases much faster—with the square of these dimensions. Thus, as is shown in Figure 51, a square one by one, with one square unit of area has four linear units of edge—one foot to each *one-fourth* of a square unit of area, whereas *a square two by* two, with four square units of area, has *only eight units of* edge—proportionately less than in the *first case, or only* one unit of edge to each one-half of a



square unit of area. So with each increase in area there is a smaller increase in edge, rendering the center portions of a surface constantly more efficient, insofar as the escape of air away from them is concerned, as the size of the surface increases. That in some manner this law prevails throughout nature's domain is quickly discovered in comparisons of different flying animals and insects, in which there is found to be a consistent increase in the sustention per unit of area, as the amount of area increases. Thus the wings of certain small gnats carry weight only in the proportion of one pound to forty square feet, from which minimum in nature the loading progressively rises to maximums of at least three pounds to the square foot in the cases of certain varieties of the albatross, the bustard, and the Australian crane.

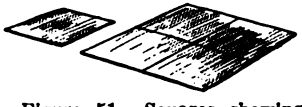


Figure 51.—Squares showing the geometrical relationships between the areas and the lengths of edge of all plane figures.

That these figures will be greatly added to without loss of efficiency is a probability of the near future. This is due to the tendency in present machines to use rather flat surfaces at very flat angles, because, as shown on Page 79, it is at such angles that the inefficient flat curve affords the highest ratio of lift to drift. But as improved wing surfaces come to be used there can be no question but that the high lifts of flat curves at bad angles will be secured with deeply-curved surfaces at efficient angles.

RELATION OF SPEED TO AREA

Other things being proportionate, the faster a wing travels through the air the more it will sustain per unit of area, it being fairly well established that the sustention increases with the square of the speed. Consequently as machines become faster the wing area required rapidly reduces. And as it is one of the peculiar conditions of aeroplane operation that it is not possible to vary the speed materially in a given machine with a given area and wing form, see Page 130, to produce a variable-speed machine it seems to be necessary to produce one with variable area.

Variable Wing Areas, while common with all birds, have not yet been provided in any successful flying machine. Such a system, in a way patterned after that of the bird, is suggested in Figure 52. It is an idea of the writer's that

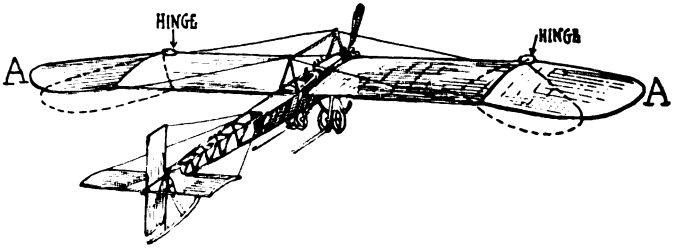


Figure 52.—Swinging wing tips. It is to be noted that the wing tips A A swing horizontally, backward and forward, on vertical axes.

if in this the wing tips AA be given down curves at their ends, thus approximating a correct wing section in two directions, as is the case with the tips of a bird's wings, the *result of swinging* them to the rear will be to increase the *sustention and tangential* components forward, while at the



same time reducing forward resistances. Close observation is convincing to the effect that such a partial folding of the wing is a method of securing higher speed employed by almost all birds.

ARRANGEMENT OF SURFACES

An aeroplane is a vehicle involving sustaining surfaces of suitable form, provided with means for propulsion, for the maintenance of equilibrium, and for steering in different lateral and vertical directions. Evidently the provision of these different elements can be carried out in a great variety of ways, which being the case it is possible to work towards the more perfect designs only by two policies—one requiring study of the laws involved in flight and the application of these laws in suitable mechanisms, and the other involving observation and copying of the flying mechanisms of nature.

In Figure 53 are shown diagrammatically the arrangements of surfaces employed in a number of well-known machines. From a study of these it will be seen that the plan most favored by the generality of aeroplane engineers is to carry the load upon one wing, or upon two superposed wings, with lightly loaded or non-loaded surfaces to the front or rear for stabilizing, balancing, and steering effects.

An exception in the case of a machine that has really flown is that of the Dunne machine, in which the peculiar arrangement of the main surfaces seems to afford a gliding stability almost as great as that of some birds, the wing positions of which it imitates.

Beyond the significances that are evident upon mere consideration of Figure 53, and various explanations of details that have been previously given, there is little to be said with reference to any general principle of surface arrangement that can be said to apply in the design of an aeroplane.

A couple of important points, however, may be emphasized.

Concerning the question of biplane versus monoplane, there is no doubt but that a given surface moved through the air under given conditions will invariably afford greater support when alone than when adjacent to other surfaces.

Regarding the details of wing forms—opposed to the *dihedral angle* (see Pages 92 and 93) is the employment *of a lateral* curvature or arching that has been comm

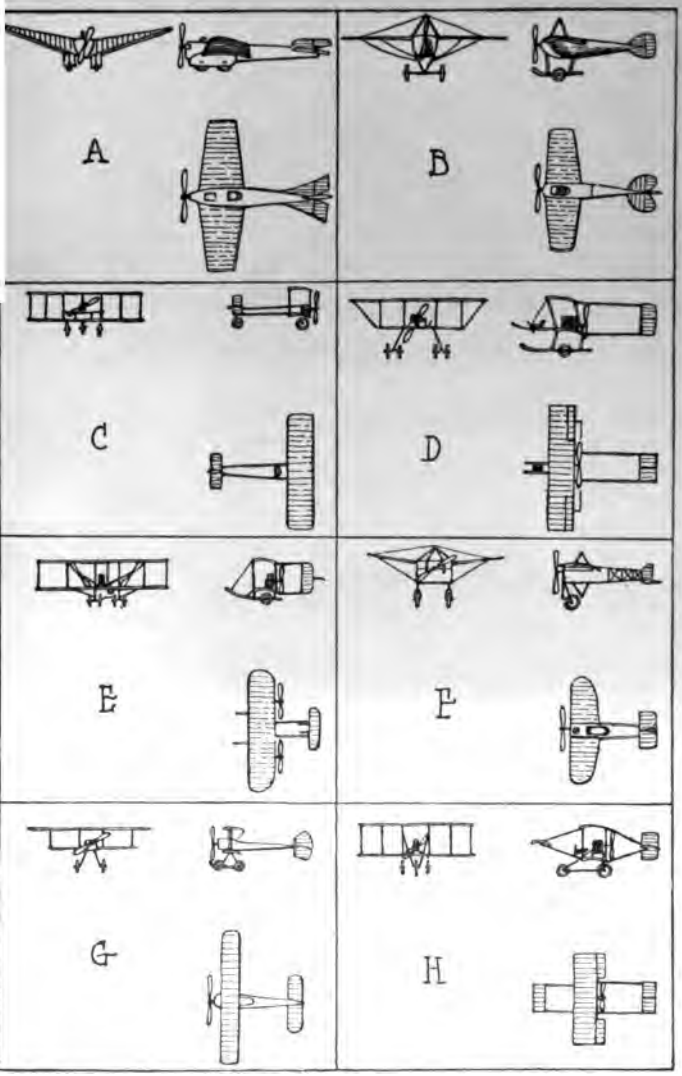


Figure 53.—Arrangements of surfaces in typical aeroplanes: A, Antoinette; B, Nieuport; C, Voisin; D, Farman; E, Wright; F, Blériot; G, Breguet; H, Curtiss.

imparted to wing surfaces for one reason or another—frequently in anything but discriminating but nevertheless effective imitation of the similar front aspect of some bird's wings. It is a proved fact that if wing ends are made to droop to a slight extent the objectionable escape of air at the ends will be considerably impeded and the sustention much improved. With a very low aspect ratio it is particularly important to have the ends of the wings droop, a feature that is especially noticeable in the case of beetles and other flying insects of the genus *coleoptera*, in which the aspect ratio is sometimes as low as two to one.

RATIO OF THRUST TO SUSTENTION

From what has been explained in previous chapters, it will be appreciated that in the design of an aeroplane it is of the utmost importance to secure by every means possible the highest ratio possible between thrust and lift, since it is absolutely upon a favorable relationship here that the efficiency of an aeroplane depends.

In aeroplanes that are now in use the thrust is rarely lower than one-fifth of the weight of the machine, from which figure it ranges to as high as one-half and even three-quarters of the weight in the case of the less efficient types. In birds, because of a most thorough incorporation of all the factors of efficiency, mentioned elsewhere herein, the drift is found upon careful measurement to be at least as low as .003 of the lift, in the cases of common soaring birds.

CENTERS OF PRESSURE AND LOADING

The center of pressure of an aeroplane surface is the lateral axis upon which the load is balanced. With wrong surfaces at wrong angles the center of pressure is a most elusive and variable factor, tending always to uncertain and precarious equilibrium, but with a correct surface the center of pressure can be most definitely located and maintained, and equilibrium secured by keeping the center of gravity of the machine beneath it.

With the machine sustained by a plurality of surfaces, the design must consider first the center of pressure of each surface, and then the mean center of pressure between these *as is suggested* diagrammatically in the aeroplane illustrat *in Figure 54.* With the loading due to the weight of

nachine then properly distributed, the balance becomes as perfect as with a single surface.

LOCATION OF LONGITUDINAL AXIS

Since an aeroplane travels through the air in a definite direction, it follows that there must be a longitudinal axis parallel with this line of motion, and sustaining definite relationships to the centers of resistance, propeller thrust, and mass.

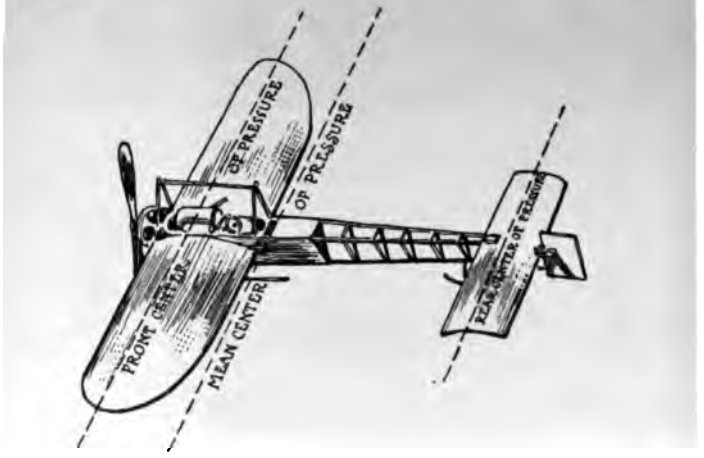


Figure 54.- The longitudinal balance of an aeroplane in relation to the centers of pressure of the sustaining surfaces.

CENTERS OF RESISTANCE, THRUST, AND MASS

The center of resistance in an aeroplane is the point above which there is just as much resistance—due to the skin friction, penetration drift, etc.,—as below, and just as much to one side as to the other.

The center of thrust, in a single-propeller machine, is along the axis of the propeller. With the machine driven by two or more propellers the center of thrust is at the mean point between these.

The center of mass in an aeroplane is the point on which it would balance if stood on its head.

Obviously, all of the three foregoing centers should be *located very close to the longitudinal axis*

If, for example, the center of mass is placed low, to secure a pendulum effect, and the center of thrust is higher, acceleration of the machine will cause it to tip forward and downward, because of its inertia.

If the center of resistance is higher than the center of mass, retardation will similarly cause the machine to tip up, because of the mass swinging forward against the resistance.

In birds all of the centers can be proved to be closely grouped on the longitudinal axis, with the possibility that under some circumstances the center of resistance may be thrown above that of the mass by the dihedral angle assumed by the wings for the purpose of landing. In this case, though, the object seems to be to cause the machine to land like a parachute, without lateral movement.

CONTROLLING AND STABILIZING ELEMENTS

In the design of the controlling and stabilizing elements of an aeroplane there is need for the utmost strength and effectiveness, since it is upon the continued ability of the operator to keep the control elements responsive to his hands that safety must in large measure depend.

AREAS AND LEVERAGES

The areas of control and stabilizing surfaces should be sufficient to produce the desired effects in sufficient quantitative values. As a general rule, it is obvious that the farther removed a controlling or stabilizing surface is from the center of loading of a machine, the greater leverage it can exert and consequently the smaller it need be. But an objection to such extreme removal of elevator, rudder, and fin surfaces as is common in a good many machines is that as the length of the lever is increased, the time demanded for it to operate is also increased. Consequently there is much to be said for placing controlling surfaces close up to the centers of loading and mass, for the purpose of insuring their quick action, at the same time increasing the areas to sufficient extents to compensate for the leverages lost.

SYMMETRY OF EFFECT

A *much-neglected* principle in the proper design of *controlling and stabilizing* surfaces, especially vertical surfac

s that demanding that they extend to equal distances above and below the longitudinal axis of the machine. Thus placed they avoid the tendency of their action to tip the machine, which is always present when they are unsymmetrical.

DEMOUNTABILITY

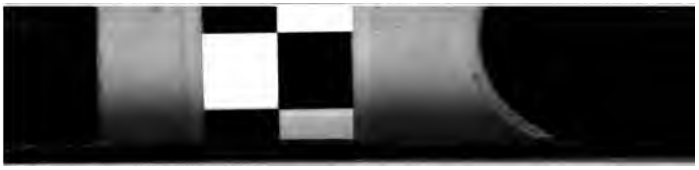
Apparently not satisfied with the altogether sufficient difficulties of making flying machines to fly efficiently, safely, and well, more than one inventor has in addition attempted o construct machines in folding form—probably inspired by the beautiful perfection of the bird's wing mechanism—with the idea of similarly quickly stowing the wings and other parts of the machine in compact and portable shape.

It being a condition involved in almost any conceivable aerial vehicle that considerable dimensions must be employed because of the necessity of operating in one way or another on large areas and masses of air, there is much of plausibility in the arguments for any scheme that appears to promise a compacter arrangement of the vehicle elements when the aeroplane is at rest, than exists when it is in the air. This seems important both for storage and for shipment, and, as has been suggested, finds its natural counterpart in all known flying creatures, which without exception fly with surfaces capable of being folded more or less completely out of the way when not in use.

But the difficulties in the way of making reliable folding wings are very great—so great, considering the present state of the art, that it seems hardly desirable to attempt overcoming them before more perfect and dependable results have been secured in the more vital functionings of flight mechanisms.

Demountability, however, is an altogether different thing from folding, this term implying simply the ready detachability and separation of different parts, with corresponding facility in reassembling, features that in several very successful modern aeroplanes are present to a considerable degree.

Undoubtedly this matter of demountability, as aeroplanes become more practical and more numerous, is one that will merit further consideration by designers, with the result that present-day shortcomings will decreasingly handicap



CHAPTER SIX

STRUCTURES AND MATERIALS

The questions of structural materials and methods of construction are among the most vital of all that the aeronautical engineer has to face. Every matter of safety and success depends largely upon the quality and reliability of the materials of which the machines are built, and the manner in which these materials are put together. Fortunately, the problem, while one of great difficulties, is possessed also of important compensating advantages. For it is becoming more and more established that successful flying machines require the use of comparatively little metal, and especially of little metal of resistant qualities worked into intricate shapes. The result is that flying-machine construction, while usually requiring much painstaking labor, does not particularly require expensive facilities, and therefore stands open to a greater number of unhandicapped amateur experimenters than almost any other field of engineering research or industrial enterprise.

Necessarily, other equipment being equal, the engineers most certain to achieve success in pioneering this new field will be those who prove the most widely informed and resourceful. For these reasons at least a smattering of a great many different trades is likely to be prolific in suggested ways of accomplishing things.

WING STRUCTURES

As the basic and most important element in an aeroplane, the wing most demands a strong, light, and in every way adequate structure, so that it may perform its various functions efficiently, reliably, and with the highest possible measure of safety.

WING BARS AND RIBS

The trend of practically all aeroplane design that has developed so far, as well as of all the engineering evidence *and data that is* accumulating, is to standardize that typ

of wing in which there is present a plurality of ribs mounted upon one, two, or more wing bars.

The extent to which the idea has prevailed that wings to work efficiently must be excessively thin, has militated against the use of wing bars sufficiently large and strong to be thoroughly safe without bracing at unduly close intervals. This is manifest from an inspection of almost any of the well-known types of machines, in which, in the biplanes, there is the common use of bridgelike trussing, and in the monoplanes, a multitude of stay wires—altogether more numerous than is desirable excepting in the cases of one or two very recent machines.

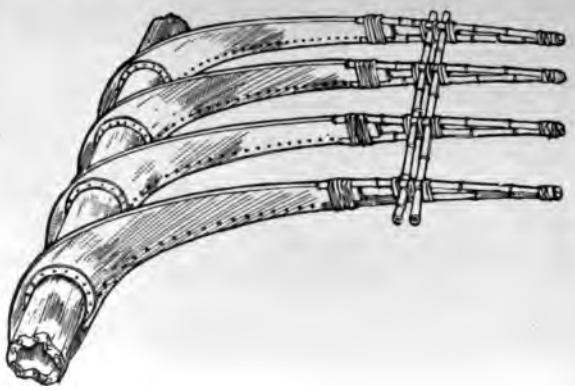


Figure 55.—Flexible wing construction, with the large front ends revoluble around the wing bar to facilitate warping without straining the structure.

The problem of rib design, aside from the difficulty of enclosing strong wing bars in thin ribs, has been a much simpler one, and with the tendency that may be expected to increase in the future, towards the use of heavy wing bars, improvement in ribs will be as certain as it will be simple. Probably comparatively thin wooden ribs, pierced at their enlarged forward ends for the main wing bar, and extended at their rears by flexible strips, will most generally find approval.

A construction developed and patented by the writer is *illustrated in Figure* 55. In this the main portion of the rib *is sawn out of a thin* board built up of crossed veneers. The

rear is made of two light and flexible bamboos, while the hole in the front end is surrounded by reinforcing plates of sheet steel. The essential feature, however, is the mounting of the ribs on the front wing bar in such a manner that they can revolve upon it, thus affording a flexibility for the purpose of "wing warping," which is absent in the usual rigid wing structure.

FABRICS

The fabrics most extensively used for wing covering so far are light percales and linens, weighing from three to six ounces to the square yard. Properly protected against the action of moisture and temperature these goods seem to serve their purpose as well as anything else that is available, though there is some probability that there may be introduced the use of light canvases for the forward edges of wing coverings, as means of strengthening the structure.

Fabric Coatings at present in use consist of a considerable variety of rubber, linseed oil, collodion, and other preparations.

In the opinion of those who have had the most practical experience with them, the rubber coatings weather badly, adding to the natural tendency of the cloth to shrink and expand with changes in temperature and failing to supply as complete protection as might be expected from moisture. It is possible that development in the direction of more heavily-rubberized cloths, like some of the heavy surgical sheetings long on the market, might afford improvement over the slightly impregnated, or "frictioned," fabrics now in use.

The objection to linseed-oil coatings, which were first developed for balloon envelopes, is that it is almost impossible to prevent them from remaining sticky, or becoming sticky as a result of exposure to the sun or warm weather. Some linseed-oil varnishes, however, have almost the smoothness of patent leather, and it is probable that further experiment by competent chemists might result in compounds of this character more serviceable than anything at present available.

Probably the best fabric coatings at present in use are those with a collodion base, consisting of guncotton or celluloid shavings dissolved in amyl acetate or ether. It is often objected that this sort of a coating is inflammable, and this is, of course, a serious objection, but it is a

ot so generally known that rubber coatings are practically s bad from this standpoint.

An objection that applies to almost all of the present fabric oatings is their failure to produce sufficiently smooth sur- aces. According to researches made by Professor Zahm, kin friction does not vary greatly between one type of smooth surface and another, but with a surface presenting minute inequalities, such as are due to the nap of a fabric, there is a much greater disturbance of the air currents and consequently higher skin friction. This would make it eem plain that the ideal coating, in addition to being weatherproof and fireproof, must glue down all of the loose fibres on the surface of the wing covering into as nearly as possible a perfect smoothness.

A practice that is commencing to establish itself is the commendable one of coating wing surfaces after they are made up, instead of making them from previously-treated fabric. The latter policy has the objection that it leaves the seams in bad condition, usually renders the cloth very hard to sew, and leaves the stitching unprotected from moisture that will eventually rot it.

THE BODY

From the explanations in Chapter Three, concerning the desirability of stream-line forms as the best adapted for movement through the air with a minimum expenditure of energy, it is clear why a shape like the body of a bird is the best. And it is equally apparent that such a body does not differ greatly from the forms utilized in some types of boats.

BOAT FORMS AND STRUCTURES

Because of obviously similar requirements of lightness and strength, if it be accepted that substantially the boat form is the proper one for an aeroplane body, it rather logically follows that standard boat structures must be of equal usefulness. The most superficial consideration of the long-developed and really remarkable structure of light canoes and other boats confirms this opinion. So it seems safe to assume that combinations of ribs, longitudinal members, and canvas or thin wooden sheathings similar to those employed in canoes is the ideal construction for an aeroplane body—



with, of course, the minor modifications of form demanded by the different purpose. The further advantage of this construction is that it affords a considerable safeguard against serious mishap in the case of inadvertent landing upon water, which with present types of machines has already occasioned fatal accidents, but which with a boatlike hull as waterproof and strong as it may be easily made is a type of accident certain to lose most of its terrors when unaccompanied by an abrupt fall, or the condition of being lost far from the hope of rescue.

HOUSING AND PROTECTION

Though this has been a point so far much neglected in the design of aeroplanes, the housing of the operator to protect him from the weather, and from injury in the case of the minor falls and breakages that need not necessarily cause death, is a matter certain to receive increasing attention in the future.

It is no less than criminal, and is wholly unnecessary, to design an aeroplane in so clumsy a way that the operator is seated on the front of a flimsy structure, with a heavy motor mounted behind him in such a position that it would be likely to kill him in a fall from a curbstone, not to consider a plunge from a somewhat greater height.

With the motor in front, a substantial landing gear beneath him, and an abundance of protection in the way of an enclosed housing surrounding him, an aeroplane operator is much less likely to be killed than in the generality of present machines. This is because a large majority of accidents do not involve falls from very great heights—a fact not so singular as it might appear when it is considered that it is on the shores of the aerial ocean, that is to say, close to the ground, that the air is most disturbed, and therefore most likely to occasion loss of control and upsetting.

THE LANDING GEAR

No part of an aeroplane calls for more careful consideration of every detail of its design than is demanded in the landing gear. Besides constituting a serious element in the forward *resistances*, if it is not properly designed, there is *the further fact that* a proper landing gear is called upon *serve not one but* a number of important functions.

PROTECTIVE FUNCTION

This use of the landing gear to afford an elastic and protecting structure that, as it may be smashed, cushions the shock and thus lessens the danger to the operator, has been referred to in a preceding paragraph.

AN ELEMENT IN THE WING BRACING

Particularly in monoplanes, but to some extent in most biplanes, the landing gear affords a point of attachment for wing stays, warping wires, etc., of the greatest importance. And in a well-designed machine, it being desirable to have such tension members fastened as low as possible and therefore made to hold at the most favorable angles, their attachment to the lowest and most widely separated points of the landing gear is the only logical policy from every engineering standpoint. That a strength commensurate with the importance of the use should be provided, can scarcely need emphasis.

PROPELLER CLEARANCE

As a prime condition determining the height of a running gear, the clearance necessary between the propeller and the ground is perhaps the most to be considered. Especially now that there is a tendency towards, and the accumulation of reasons for the use of propellers of very large diameter and low rotational speeds, the landing gear needs to be high, which in turn demands that it be built strong and that the resistance it offers to movement through the air be reduced to a minimum.

GROUND ANGLE AND FLYING ANGLE

Another reason for high running gears in at least such types of machines as the more conventional monoplanes, with horizontal rudders or elevator surfaces at the rear, is the need for a ground angle at starting different from the flying angle, once the machine is launched in the air. This is very evident in the operation of most present-day monoplanes, which stand upon the ground with the wings at an excessive angle of incidence, but which, because of the tail's lifting first, run on the ground with the angle very flat. Then, by *steering the tail* down, the angle of incidence of the wings *is again brought* to a maximum for the leap into the air, after

which the flying angle becomes very nearly the same as that for the run on the ground.

RUNNERS AND WHEELS

Since it is the fundamental function of the landing gear to enable the safe starting and landing of the machine, considerable experimenting has been done with various systems of wheels and runners. The use of wheels or runners alone was the first construction, and the former is still persisted in by a few prominent designers, but by all means the preferable scheme seems to be a combination of wheels with runners, so that the wheels may afford ease of starting without the now-obsolete use of special launching devices, while the runners will act as brakes in landing, and span inequalities of ground certain to wreck a wheel, thus simplifying the problem of coming back to earth without a smashup.

THE HYDROAEROPLANE

A recent development in aeroplane design, commencing with Fabre in France and even more successfully continued by Curtiss in the United States, is the hydroaeroplane landing gear, enabling an aeroplane to start from and descend upon water surfaces. In the best of its present forms the hydroaeroplane may be defined as consisting of any ordinary type of machine, provided with one or more hydroplane floats, in form like hydroplane boats.

Undoubtedly this type is capable of great development, and will lead in time to a very considerable use of water areas for the landing and debarkation of machines.

A curious development from the hydroaeroplane, which so far has made very little progress but which nevertheless offers some interesting possibilities, is a hybrid type of water-air vehicle consisting of a hydroaeroplane boat, provided with wings not capable of lifting it clear of the water, but of sufficient area to carry almost all of its weight. Very high speed has been attained in the case of at least one machine of this type, the first trials of which, however, were conducted on runners, over a frozen lake surface.

COMPRESSION MEMBERS

Important elements in aeroplane structures are the com*pression members*, which are, indeed, of the greatest impo*tance in engineering* structures of any type.

WOOD

Not without a considerable basis of fact has it been asserted that the flying machines of the future will be built in the carpenter shops of the future, for wood is by far the most utilized material in all successful fliers. For wing bars and ribs, runners and running gears, frames, braces, and the like, wood seems as serviceable and indispensable as it is for the rims of bicycle wheels, besides which, it is cheap and easily worked.

It is not generally appreciated, even by many engineers, that certain woods constitute almost the strongest, most reliable, and most durable of all structural materials, the best qualities of selected timber being, weight for weight, close rivals in absolute strength—compressive, tensile, shearing, and even torsional—with all metals but the very finest alloy steels, while in immunity from flaws and uncertainty in regard to physical properties woods are even superior to metals, especially when well seasoned. Unseasoned woods, besides being heavy, are often less than half as strong as the same timbers thoroughly dry.

METAL TUBING

Certain of the metals, in the form of thin-walled tubing, afford excellent structural members, combining lightness with strength and stiffness. This is well attested in the widespread use of steel tubing for bicycle frames, in automobile manufacture, and in many other applications.

Of the sorts of steel tubing regularly on the market, the most common are carbon steels, in soft, medium, and hard-drawn grades, but not very high quality. Stronger than these but not so good for withstanding shock loads and vibration are the tool-steel tubings. Of alloy steels, 3½ percent nickel steel can be had in the form of tubing, and there also are some vanadium-steel tubings on the market. It is rather difficult to draw alloy-steel tubing in as large diameter and with as thin walls as most engineers consider desirable for aeronautical structures.

Of the metals other than steel that can be had in tubing form, and which are of sufficient strength within a given weight to receive serious consideration from aeronautical standpoints, there are only the aluminum alloys. Of these none really excel even the poorest steel except in their re-

sistance to rust. This latter quality, however, occasionally dictates in some situations the use of magnalium, chrome-aluminum, wolframinium, and possibly a few others among the secret or less well-known combinations of aluminum with other metals.

COMBINATION STRUCTURES

Metal tubings are manufactured extensively in round sections only, though limited quantities of oval, square, and other sections can be had on special order. These are, however, in addition to being difficult to obtain, heavier and less strong than cylindrical tubing, while really correct stream-line sections are practically out of the question.

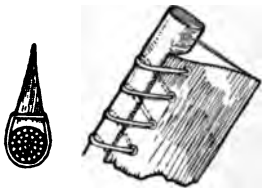


Figure 56.—Wire cable and metal tubing built up into stream-line sections by the addition of wooden strips.

This renders it possible that built-up members, constituted of a piece of steel tubing with a wooden re-enforcement, something as illustrated in Figure 56, may find more or less extensive application as aeronautical engineering progresses.

JOINTS

The jointing of compression and other members in an aeroplane structure, so that the joints shall be secure and reliable, and not less strong than the elements they fasten together, is by no means a simple problem.

Bolts passed through wooden or other members inevitably weaken them, and unless the greatest care is taken to provide additional material around bolt holes the danger of collapse is an ever-present and a serious one.

A particular point to be observed in bolting wooden members together is to bore bolt holes loose enough so that the bolts will pass into them freely, so as not to set up splitting stresses, which are unavoidable when the fits are too tight. The use of bolts passed through the ends of steel members is hardly as objectionable as their use through wood, though in this case re-enforcement is still desirable.

Sockets of cast aluminum or of formed-up sheet metal, into *which compression* members may abut and be held in place *by the tension* members that maintain the compression,

common expedient with biplane builders. An objection to his sort of assembling is that if any portion of the structure breaks or loosens up, all of the rest is likely to go to pieces, a result not so likely to ensue if every joint is made secure, independent of what may happen to any other joint.

Brazing as a means of putting together structures of steel tubing is probably the best available, having been long tested in bicycles and automobile construction. The only special comment concerning this process that might be of help to an aeroplane builder has reference to the fact that it is exceedingly difficult to produce secure brazed joints in steels containing nickel. Indeed, it is very much of a question whether very hard silver-solder is not better with these steels, because of its superior adhesion.

Brazing with copper instead of with spelter is also found to give a superior result.

Clamps, as means of attaching different elements together without the necessity for bolt holes, constitute a very serviceable expedient when properly designed and discriminatingly employed.

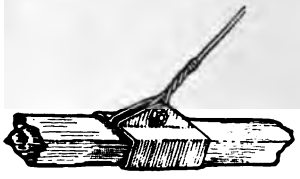


Figure 57. — The Nieuport clamp for attaching stay wires to wing bars, etc.

The type of clamp used on the Nieuport monoplanes for the attachment of the wing stay wires is illustrated in Figure 57. This particular use, however, has been severely condemned by many experts because of the evident danger of its slipping, in which case a terrible accident could not fail to result.

Lashings of wire or cord, alone or in combination with metal re-enforcement, constitute very light and secure means of putting wooden and other structures together. Many examples of lashed joints in boats, weapons, and the tools of prehistoric and savage peoples are really remarkable examples of sound engineering detail, the use of sinews, rawhide thongs, and fiber lashings having been evolved to perfection through many centuries.

A system that the writer has found very satisfactory for putting together bamboo and other wooden members is illustrated in Figure 58, the essence of the scheme being the

employment of sheet-steel plates introduced into saw cuts in the wood, the lashing then applied and the whole kept secure by the lugs **A**. Larger lugs, also provided with holes for the attachment of wires, are shown at **BB**. By using, instead of single sheets of steel, double or triple sheets of thinner stock, failure through flaws is made almost impossible.

TENSION MEMBERS

The employment of tension members in an aeroplane is exclusively a feature of man's devices for the accomplishment of flight, since they are absent in birds and other flying animals in which compression and girder members constitute the structure, though there are tension elements in the way of muscles and sinews used for the manipulation of the different elements.

WIRES AND CABLES

Wires, and cables composed of wires, are the only possible materials to use for the tension members of an aeroplane structure, nothing else being sufficiently strong, light, and compact. Preference is given by the most experienced to steel of the finest qualities, and though magnalium and phosphor bronze wires are very strong, these are not as strong as steel.

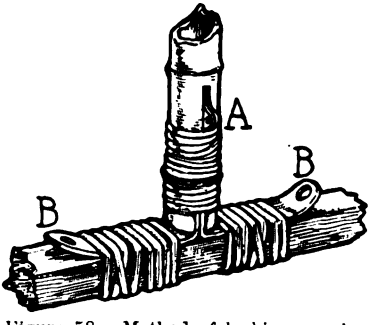


Figure 58.—Method of lashing wooden struts together by the use of steel plates and wrappings of wire

The strongest steel wires are the high-carbon music wires, and alloy-steel wires of the chrome-nickel and vanadium-steel varieties. An objection to the very strongest wires that can be produced is that they are apt to be brittle, and thus fail from flaws or bending, so better results are usually to be secured by a slight sacrifice of strength in favor of reliability.

Good carbon-steel wire will withstand gradually applie*stresses of as high* as 300,000 pounds to the square inch

ore breaking; chrome-nickel and other alloy-steel wires may o even as high as 450,000 pounds to the square inch, and at he same time be less brittle than carbon-steel music wire. Milder steels range from 60,000 to 100,000 pounds to the quare inch, and at these strengths may be so soft and horoughly annealed that soldering will not reduce their strength—a considerable advantage in some systems of assembling. Phosphor-bronze wire will sustain as much as 100,000 pounds to the square inch, and magnalium 70,000 pounds to the square inch, the latter, considering the extremely light weight of this material, being a very high strength per unit of weight—though not of section.

Minimization of Resistance of wires moving through the air with the structure to which they are attached is an important consideration in aeroplane design. No very accurate or consistent figures are available as to the exact resistances set up by wires of different sections at different speeds, but it is well established in a general way that this resistance is enough to be of serious moment in a great many machines. The reason for this seems to be that the vibration of the wires causes them to disturb much more air than would be expected from the total projected area of the wires, with the result that this greater amount of disturbance greatly increases the resistance.

From the foregoing it is evident, other things being equal, that the best design is the one in which the wires are few and comparatively heavy, so as to cut down their aggregate length and at the same time reduce the tendency to vibration. This policy also makes practicable a further minimization of the resistance by the application of wooden strips of streamline form to the backs of each cable—much as in the case of the built-up structure illustrated in Figure 56.

ATTACHMENT OF ENDS

The secure and safe attachment of the ends of wires and cables to the different points on the structure is of course of the utmost importance, and should be carried out in the most thoroughgoing engineering manner.

Spliced and Lashed Eyes in cables are the common means of attaching them for all sorts of uses, as in the rigging of *ships, mine* and elevator hoisting apparatus, etc.

Splices, though more difficult to make, are undoubtedly

better than lashings, and by a good workman can be made as strong as the cable itself, as well as remarkably neat in appearance.

A metal eye is always advisable to line the loop, as illustrated in Figure 59.

In lashing, the cable is simply bent around such a metal eye as that illustrated in Figure 59, and lashed to itself by a wrapping of fine wire.



Figure 59.—Spliced eye in wire rope.

Piano Loops and other wire terminals in considerable variety have been developed for securing the ends of single wires.

It is a remarkable fact that the piano loop, illustrated in Figure 60, and the quality of which has been proved by development through a century of piano building under conditions of tension and vibration load fully as severe as in an aeroplane structure, has been applied to aeroplane construction by only one investigator, Montgomery, who first used it in 1884.

This loop is not quite as simple as it appears, and in its best form requires to be made with a special twisting machine, which while wrapping the two wires symmetrically around each other, draws the loop along with a receding



Figure 60.—Piano twist in wire end.

screw so that there is a regular number of turns to the inch. At the same time the two ends of the wire are permitted to revolve freely as the twist is made, so as to prevent twisting the wires within themselves at the time they are twisted around each other.

The small closed coil at the end of the wire is more a matter of disposing of the end in a neat manner than it is of adding to the strength, which in the case of a good piano loop is at least ninety percent of the strength of the wire.

No soldering or other treatment objectionable from the *standpoint of* using a heat-treated and tempered wire is i*volved in the* case of this twist, and it absolutely will not

ut, though a slight give occurs as it sets itself the first time ension is applied to it.

Other wire terminals, not so good as the piano twist, but nevertheless widely used, are made by carrying the end of the wire around and through a short section of brass or steel tubing with the end finally terminating in a hook as illustrated in Figure 61. Tests prove that this type of attachment does pull out under very heavy tension unless soldering is resorted to, in which case the wires are very much weakened by the consequent annealing.

Wire Lashings, consisting of rings or links built up of turn after turn of wire all soldered into a mass when the ring is completed, constitute a safe and unfailing means of applying the loop end of a wire to its point of attachment on the structure. Obviously it is inconceivable that two or more adjacent turns in such a ring could possess such adjacent flaws as could possibly cause breakage.



Figure 61.—A common means of affixing wire end by use of short section of tubing.

TIGHTENING

Since the tension members are the last to be applied in a structure, while upon them the rigidity of the whole in a large measure depends, the provision for drawing them tight is very important.

Turnbuckles are the most used devices for tightening wires and cables, having long ago been developed into practical and efficient forms for all manner of other purposes—their employment in the rigging of sailing vessels being possibly that most nearly analogous to their use in the structure of aeroplanes.

An objection, however, to such turnbuckles as have been and are marketed by the ship chandlers is the very excessive weight necessary to secure a sufficient strength with poor qualities of material. Also, such turnbuckles are not commonly provided with sufficiently secure means of preventing them from coming loose, to meet the approval of the competent aviation expert.

The consequence is that aeroplane development has brought into the market various types of special turnbuckles, made of exceedingly high quality materials, and generally provided



with locking means. Probably the best are those in which the two screws, provided with eyes for the attachment of the wires or cables, screw right hand and left hand into the centre barrel of steel or bronze. The latter is not as strong as steel, weight for weight, but the addition of a little weight to make it strong enough is recommended by many as a means of preventing such rusting as in the all-steel type of turnbuckle sometimes makes it difficult to unscrew. Splitting the ends of the turnbuckle barrel and providing them with lock nuts is one approved means of preventing unscrewing. A clumsier but more reliable expedient is to bend a soft wire through the two eyes of the turnbuckle, its centre portion passing through a hole drilled through the turnbuckle barrel.



Figure 62.—Turnbuckle made from a bicycle spoke.

A much-used type of turnbuckle can be extemporized from heavy motorcycle or bicycle spokes by bringing a portion of the spoke around into an eye, the usual spoke nipple being applied to the other end and passed through a sheet-steel swivel, bent back and provided with holes for the attachment of the other wire, as illustrated in Figure 62.

GIRDER MEMBERS

Many of the heavier members in an aeroplane are required to resist lateral or buckling stresses as well as compression stresses, for which reason girder construction of one kind and another must come into increasing use as the tendency to dispense with superfluous wiring progresses.

A particularly strong and light type of girder is the hollow wooden spar, highly specialized by builders of small sailing craft and high speed yachts. Particularly for wing bars do such special spars seem desirable.

CONSTRUCTION AND EXAMPLES

Another place for the use of girder construction as a mean*s of avoiding mazes of* external wiring is in the body of a n*chine. Most of* the advanced monoplanes, and a few bipla

re built with bodies equivalent to the typical box or lattice irders long established in bridge and structural engineering. uch bodies are very strong and light, and such development s may take place in the direction of tapered stream-line odies, boat-like in their general appearance as well as in much of their structural detail, does not necessarily mean that the fundamental principles of the box girder need be discarded.

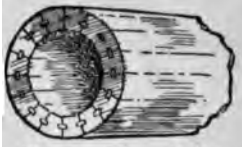


Figure 63. — Hollow-spar construction for wooden wing bars.

The best construction for a hollow wooden spar is that illustrated in section in Figure 63, in which the small tongues between the main sections are to prevent the latter from springing apart under a heavy buckling stress.

CONTROL ELEMENTS

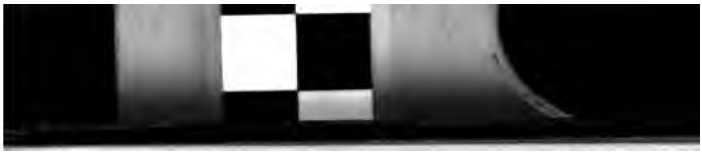
In no part of an aeroplane is there demanded more careful and well considered design than in the different control devices, failure of which is exceedingly likely to terminate in fatality. The necessity for controls to be simple and easily operated is almost as imperative, since complication of manipulation may easily lead to the sort of confusion in an emergency that often results in accident from the ever-present personal equation, even though there be nothing broken about the apparatus.

SIMPLIFICATION OF CONTROL

The number and complexity of controlling movements involved in the operation and piloting of an aeroplane have long constituted one of the greatest bars to progress in this field of engineering, and still present some of the most difficult of its unsolved problems.

Man being a creature possessed of only two feet and two hands, and flight ordinarily requiring—as displayed by the birds—a variety of manipulations delicate and vigorous, quick and slow, simple and complex, which man can scarcely hope to imitate, the difficulty of producing them in unfailingly effective coördination must be apparent.

Manipulations involved in controlling devices are in their *number directly* proportionate to the effects it is sought to *produce by* movement of controlling surfaces. Thus there



may be lateral and longitudinal balance to be maintained, vertical and horizontal steering to be effected, a motor to regulate and adjust, instruments and devices to be watched, and the special conditions of starting and landing to be encountered—from all of which it must appear that the average aviator will find more than enough to occupy his attention unless the number of these functions is reduced to a minimum.

CONTROL STRESSES

The loads on controlling surfaces, and, consequently, upon the wires, levers, etc., by which they are manipulated, are so very light in all ordinary aeroplanes, unless most disadvantageous leverages are employed, that there is not the slightest excuse whatever for such breakage or other failure of the parts as all too frequently have resulted in terrible accidents.

The Magnitude of the Loads is of course the measure of the strength that must be provided in the wires and other controlling elements, but even after allowing for the highest possible unit pressures on the surfaces it is still possible to provide immense factors of safety without using heavy connections.

The Balancing of the Loads is a detail that can be so arranged as to require from the operator a manual effort very much less than the stress upon the controlling elements. Thus in a wing-warping control as one of the wings is drawn down the other rises, and the pressure under the rising wing so nearly balances that under the other that practically the only effort needful to be exerted by the operator is to overcome the friction of the operating device. Similarly, elevators and horizontal and vertical rudders should be pivoted sufficiently close to their centres of pressure so that moving them or holding them in fixed positions can in neither case require a powerful effort.

PULLEYS AND CHAINS

A point in the design of controls that is much slighted in present aeroplanes is the provision of sufficiently flexible and frictionless elements where the power is transmitted around corners, as over pulleys and the like. Particularly to be condemned is the common practice of sliding flexible wire cable through bent copper tubes, which easily set up friction

loads at each point of this character equivalent to a material percent of the entire effort transmitted. And, more than this, such wear as does occur is likely to be concealed by the tubing and thus progress to the point of danger without being noticed.

The use of cable chains or other flexible chains, passing over ball-bearing pulleys, does not add greatly to the cost of a machine, and has the advantage of transmitting power with so small a percentage of loss that the resulting effect is immensely superior to any to be secured by the use of flexible cable with or without plain-bearing pulleys. And as friction always means wear, any reduction of it makes for safety.

RELIABILITY AND SAFETY

These are, in the last analysis, absolutely the most important of all the considerations that can influence the design of a control system.

Duplication and Inspection are the twin means to absolute avoidance of the possibility of accident. Making every controlling element plural, with the operativeness of each part wholly independent of anything that may befall an adjacent part, is the sure way to guard adequately against flaws in material, undiscovered wear, and other unforeseen occurrences that may cause disaster, and since such duplication cannot at the most add very measurably to either weight or

CHAPTER SEVEN

POWER AND PROPULSION

The question of power for the propulsion of aeroplanes is one at the present time of the utmost importance. So far, aeroplane progress has been made possible largely through the development of light-weight gasoline motors involved in the growth of the automobile industry. And undoubtedly a most serious obstacle in the way of immediate further progress is the lack of motors still lighter, more efficient, and more reliable than the best of those available. Most aeroplane flights so far made for duration records, for example, have been terminated by motor failure, though close behind this limitation always has been that of fuel radius, which is largely dependent upon the matters of weight and efficiency.

It nevertheless is obvious that many of the best flying machines of the present time might have been flown with much heavier motors than are now used in them—with motors such as have been available for even twenty or thirty years—and there is every reasonable prospect that as progress continues still less power will be required, until ultimately flight may be accomplished by man with even as little power per unit of weight as is demanded for the flight of birds, thus in a manner making the motor problem solve itself—by so reducing the demand for power that almost any sort of a motor will serve the purpose. But it has seemed necessary first to apply the light weight motor as a means of working out the general details of the necessary aerodynamic mechanism, the discovery that heavier and less powerful motors could conceivably have been used at a much earlier period being knowledge secured too late to have been utilized to the utmost advantage in flight development.

AMOUNT OF POWER REQUIRED

It is constantly becoming more evident that the amount of power required to fly an aeroplane can be more and more reduced by improving the efficiency of the aeroplane itself. *Thus, in the use of* stream-line bodies and other elements

n improvement of the aerodynamic efficiency of wings, and n reduction to a minimum of skin friction, lie the solution f flight with a minimum of power.

LEVEL FLIGHT

What may be considered the normal type of flight is flight along a level course—the machine neither rising nor falling—and this type of flight is the proper measure of the normal energy requirement.

As has been heretofore explained, such are the efficiencies of aerodynamic reactions that the power required for level flight tends to become extremely low as aeroplanes make progress towards correct designs, just as it is extremely low in the case of nature's mechanism, the bird.

CLIMBING

In rising from a lower to a higher level, much more power is required than for level flight, the amount of this maximum energy requirement being, in fact, determined by the climbing ability demanded. This brings to attention a somewhat curious condition, which is that increasing the power and the thrust by which an aeroplane is propelled can not and does not materially increase its speed, but simply forces it to progress on an upward slant, gaining in altitude rather than in rate of travel.

GLIDING

Just as climbing with an aeroplane takes place without material variation in speed, but demands an increase in power, so, conversely, gliding does not ordinarily increase speed, but simply diminishes the demand for power. Thus, if the power is cut off when an aeroplane is in the air, if it is properly designed and properly steered it cannot fall but will commence at once to coast on a slant of air at its normal speed, just as completely and safely under control as in any other condition.

Soaring Flight is a peculiar and as yet unexplained type of gliding flight, concerning both the performance and the mystery of which there is much dispute. Authorities there are, whose practical knowledge is as indisputable as are their theoretical attainments, who stoutly contend that it is going to be possible ultimately to achieve without power *something akin* to the indefinitely continued soaring flight



that is so indubitably established to exist in the case of the larger flying birds. A simpler explanation, but one that unfortunately does not explain all cases if many dissenting authorities are to be believed, is that the soaring bird derives sustention from upward currents of air, caused by wind friction over surface contours or by ascending streams of heated air, permitting the bird, so to speak, to coast indefinitely down an invisible hill that itself rises faster than the bird coasts down.

POWER PLANTS

A question not of less importance than that of the amount of power required to propel an aeroplane is that of the source from which it is to be obtained.

GASOLINE ENGINES

The gasoline engine in certain highly specialized forms being the lightest prime mover known, and it having been developed to high degrees of reliability as an element of motor boats and automobile mechanism, it is the only motor that at present meets any considerable favor or that may be considered to offer material promise for future application to aerial vehicles. Aeroplane engines using gasoline as fuel have been built weighing as little as a pound and a half to the horsepower, and are made of considerable reliability in weights of from two and a half to seven pounds to the horsepower—the latter figure permitting thoroughly adequate water cooling and including the weight of all necessary adjuncts, such as ignition and carbureter equipment, flywheel, radiator, and the like.

Examples and Data concerning various established aeroplane power plants are much more informing than any merely general consideration of the subject.

By far the most successful as well as one of the lightest aeroplane motors at present in use is the Gnome—a revolving-cylinder type, all of the parts of which are machined from bars of high-grade alloy steel. This motor in its different models weighs from two and two-tenths pounds to four pounds to the horsepower, and is capable of running for at least as many as ten hours without stopping, constantly delivering its maximum power output.

Despite the fact that when first placed upon the marke

was regarded as an exceedingly freakish variation from accepted automobile practice, the Gnome motor has vindicated the originality of its designers by securing for aeroplanes in which it has been installed practically every aeroplane record of importance within two years from its introduction. It possesses, however, serious disadvantages in combination with its important advantages. Most valuable of the advantages are the very considerable flywheel effect due to the large revolving mass, the immunity from vibration due to the fact that none of the parts really reciprocate except relatively to one another, and extreme lightness and effective air cooling, due to the fact that the whole construction especially lends itself to these desiderata without sacrificing strength or reliability.

The most objectionable features of the Gnome motor are the gyroscopic effect due to the revolving mass, the amount of power required to revolve it against the air resistances, the great space it occupies, and the excessive oil and fuel consumption.

Contrary to common opinion, the cooling of the Gnome motor is not so much due to the revolving of the cylinders through the air as it is due to a wasteful internal scavenging effect of the incoming charges through the valves in the pistons, whereby the usual tendency to overheat in these elements is largely counteracted. Another condition that contributes to the effective cooling is the very low compression employed, disadvantageous otherwise, however, in that it manifests itself in a power output not over fifty percent of that commonly obtained from the same cylinder capacity in ordinary automobile engines.

In accounting for the cooling efficiency of this revolving motor, it is usual to consider the path of the cylinder a circular path, which is the condition only when the machine is not progressing through the air. But with the normal forward movement in flight of a definite number of feet to each revolution of the motor and propeller, the path of the cylinders through the air becomes a helical path—around a helix so elongated as to add but a small percentage of the distance the cylinders would travel did they not revolve.

Especially clever in the design of the Gnome motor is the *quite original* use of a "master connecting rod," to the big *end of which* those of the other pistons are linked in such a

manner that, while their angularity is slightly increased, there is afforded the very great advantage that the big ends of all the rods except the master rod become rocking rather than rotating bearings, and permit that of the master rod to be provided with a large ball bearing of a type that reduces friction and minimizes wear.

The apparently paradoxical fact that the pistons and connecting rods of the Gnome motor do not reciprocate but do really revolve will be understood when it is considered that the crankpin is stationary, so that the pistons, linked to it by the connecting rod, are compelled to revolve in a circle around it. This circle is eccentric to that around the main bearing of the crankshaft, about which the cylinders revolve, wherefore there is a relative reciprocation between the cylinders and pistons, due to their traveling two eccentric circles, but no actual reciprocation with reference to anything external to the motor.

With the exception of the revolving motors, there are no conspicuous examples of successful air cooling in aeroplane-motor practice, with the possible exception of the Renault motors, which are air cooled by powerful blasts of air forced over the cylinders by a centrifugal blower.

Typical of a more conservative school of aeroplane-engine design are such motors as the Wright, the Panhard, the Curtiss, the Antoinette, and other fairly close approximations to what is standard in automobile engineering. In these water-cooled motors a high degree of reliability and durability is sought rather than extreme light weight, but it is only as aeroplane efficiencies become higher and the consequent demand for power lessens that motors as heavy for their power as these really can come into their greatest fields of usefulness.

As in automobile engineering, a common type of water-cooled aeroplane motor is that with four vertical cylinders, but preferred to this where greater power is required is the "V-shaped," eight-cylinder construction, involving two rows of four cylinders each, placed at ninety degrees to each other, thus permitting the use of an ordinary four-cylinder crankshaft for the eight cylinders, and allowing especially neat, compact, and fairly light weight construction.

Another engine type of much promise, and of some prese*application, is* the horizontal-opposed motor with two

inders. Mechanically, this is even better balanced than ordinary four and eight-cylinder motors, and, while it does not lend itself to the development of as much power within as low weight as in multicylinder constructions, it is probable it will afford enough from every standpoint of future requirements.

STEAM ENGINES AND BOILERS

The steam engine, though it has not yet been applied to modern aeroplanes, was extensively used in the early era of aeroplane experimentation, and may again disclose very definite merits if future progress sufficiently reduces the power demand. For in addition to its high reliability, not the least of the advantages of a well designed steam power plant is the possibility of providing for the use—even in one and the same plant—of a great variety of common fuels, readily obtainable anywhere.

In the matter of reliability, it is well known that certain automobiles with steam power plants, besides being substantially as light as are the best gasoline automobiles of similar capacity, are well in advance of the average in reliability and durability—though it is a fact against them from automobile standpoints that they require unusually expert care and handling.

Concerning fuels, liquid fuels such as gasoline and kerosene are most used in steam automobiles. But with the constant and unvarying power demand of the aeroplane, which thus escapes the necessity for regulating devices capable of taking care of considerable fluctuations, there is more than a reasonable possibility of using various solid fuels such as coal, coke, charcoal, wood, etc., most of which have the merit of almost universal availability, so that a machine utilizing them could find fuel by descending in almost any locality.

One of the most interesting steam engines ever built was that used by Sir Hiram Maxim in his aeroplane experiments in 1894. This engine weighed, with the boiler but without water, about eighteen hundred pounds, and developed 363 horsepower—less than five pounds to the horsepower.

Another very light aeroplane motor was the steam engine used by Professor Langley in his successful model flying machine, which flew half a mile over the Potomac River in 1896. This engine weighed, with its boiler, only eight pounds,



and developed one and one-half horsepower. Other interesting steam power plant, built in 1893, by Laurence Hargrave, were applied to models successfully flown in Australia. In these was incorporated one of the first examples of tubular boilers of the now widely known flash-generator type. The most powerful of the Hargrave motors developed over five-eighths of a horsepower and weighed only seven pounds—engine, boiler, burner, and enough fuel and water to last for four minutes' running.

For successful application of steam to aeroplane uses there is no question but that the flash generator, found most successful in automobile practice, must be used in combination with such engines as also have been found successful for the propulsion of automobiles.

TANKS

While admitting of no considerable choice in design, and though essentially simple in construction, there are nevertheless a few points worthy of emphasis in reference to the fuel, lubricating oil, and water tanks involved in one type and another of aeroplanes.

Heretofore it has been rather a common custom to provide tanks elongated so as to offer a minimum resistance to movement through the air, but though such minimization of resistance is important it would seem that other questions, such as maximum capacity with a minimum of weight, ample strength, and an avoidance of splashing of the liquid contents, might be of even greater importance. From these several standpoints everything is in favor of spherical tanks—the sphere being the one form that does not tend to distort under internal pressure, besides which it is the form that affords a maximum capacity with a minimum of surface. Another advantage of the spherical tank is that tilting and rocking movements of the machine cause the tank to revolve around its contents instead of splashing them violently about.

The matter of air resistance is easiest taken care of by enclosing the tank or tanks in a stream-line body, in preference to attempting to make them of stream-line form themselves.

PROPELLERS

The screw propeller has been quite thoroughly determin
to be by far the most efficient device for securing th

against the air for the propulsion of an aeroplane with a minimum waste of the available power. In addition to entailing too much complication, with consequent rapid wear and constant danger of breakdown, all types of revolving saddles, flapping wings, and the like, have been found very low in their efficiency as compared with the best aerial propellers, some of which, operated under favorable conditions, have been found to afford thrusts equivalent to ninety per cent of the actual power developed by the motor.

Much confusion has existed in the past and still exists in the minds of the ill-informed, who fail to distinguish between the functions of air propellers and the functions of similar but by no means analogous mechanisms. To clear away this confusion it is essential to understand that there are three possible devices of the same general appearance, which are adapted to quite different purposes. First of these is the ordinary windmill, the function of which is to rotate from the reaction occasioned by a cylindrical stream of air forced through its circle of rotation; second is the revolving fan, theoretically and practically the proper opposite of the windmill wheel, its function being the production of a current by shearing loose a cylinder of air from the surrounding atmosphere and forcing this cylinder through its circle of rotation. The third device is the air propeller, bearing no such close relationship to the other two devices in its functions as it does in appearance, and as they do sustain to each other. For an air propeller is intended neither to react from disturbed air forced through it, nor to cause a flow of air to pass through it. Instead, its function is that of progressing with its attached mechanism through the air with a minimum disturbance—as nearly as possible like a screw in solid substance. Unavoidably, when first started, or when traveling slower than its proper pitch speed, an air propeller must operate as a more or less efficient fan, but under ideal working conditions its blades slide through their helices of travel with little disturbance of air but that due to the compression and the neutralizing reactions of the air against the effective surfaces of the blades.

The design of air propellers is probably a department of aeronautical science in which there is less accurate and well *formulated* knowledge available than in almost any other. *In a general* way, however, it has become pretty well estab-

lished that the ideal propeller should have no more than two blades, and that these blades are properly to be considered as aeroplanes revolving in a circle.

As for blade outlines and sections, evidently an infinite variety can be had, and in selecting the particular combinations best adapted to afford efficient results, little more can be done at the present time than to profit from the experiments that have been made, in preference to relying on theoretical conclusions. There is no question, however, but that the same rules concerning parabolic working surfaces, placing the greatest thickness towards the front edge, and a modification of the sections and angles towards the blade tips, are at least as important in their application to propeller blades as to wing surfaces.

PROPELLER PITCH

To avoid too high a rotational speed, it is probably preferable to use propellers of very high pitch, the most efficient results so far secured being with propellers in which the pitch exceeds the diameter. Failure to design on this basis involves, to secure sufficiently rapid progress through the air, rotational speeds so high that head resistances and skin friction become of such magnitude as to consume large proportions of the power.

PROPELLER SPEED

The peripheral speed of propellers so far tried out by different engineers is known to range all the way from 12,000 to over 50,000 feet a minute, with the most favorable results in nearly all cases secured at the lower speeds, which besides their aerodynamic advantage also keep down the centrifugal stresses on the blades. At the higher of the speeds mentioned—nearly 570 miles an hour—the centrifugal pull exerted at the blade tip is such as to test dangerously the qualities of even the finest structural materials available.

Beside high pitch, low propeller speed involves large diameter and large area if the thrust secured is to be enough to fly an average aeroplane. These considerations practically demand that the propeller be driven through the intervention of gearing from the engine crankshaft, very few engines capable of developing the requisite power within a lo weight being designed to run at speeds low enough to

suitable for direct driving. Though at present most aeroplanes still employ the direct drive, because of the mechanical advantages of mounting the propeller on the crankshaft, the most efficient ones do not, and there is a growing tendency to discard direct for gear drives.

SLIP

Slip is a phenomenon that presents itself in all mechanisms, of any type, in which it is sought to produce positive movements or reactions in fluids by the action of solid parts. Thus, an air propeller, which if caused to travel through an internally-threaded cylinder of metal, would in fact as in theory progress without slip—making the definite and invariable advance demanded by its pitch for each revolution or part of a revolution accomplished—in the air ordinarily progresses at some slower rate, the difference being due to the loss of effect caused by the air being moved backward as well as the propeller blade being forced forward.

EFFECTIVE SURFACE

The effective surface of a propeller is that portion of the circle swept by the blades, against which thrust is developed. For two principal reasons there is little advantage in attempting to make effective surface of the whole of the circle. The first reason is that the speeds and the angles of blade travel towards the center of the circle are too slow and too inclined to produce measurable thrust with any sort of blade surface that it is possible to devise. The other reason is that —the areas of circles varying with the squares of their diameters—very little area is lost in dismissing from thrust considerations considerable portions of the inner end of the propeller blades. Thus to eliminate one-half of the blades, from their centers to the hub, is to eliminate only one-fourth of the complete area of the circle.

THRUST

The matter of propeller thrust is a subject concerning which there is much confusion. This is especially pronounced with reference to the distinctions and comparisons that are commonly made between "standing thrust" and "traveling *thrust.*" Nevertheless an analysis of the subject discovers it *to be much less* complex than at first appears.



With an aeroplane held back on the ground, or with a propeller otherwise restrained from traveling through the air, it then affords the highest thrust of which it is capable at the given speed of rotation. This is because in this condition, braced against an immovable point, it is shearing free from the surrounding atmosphere a maximum quantity of air and forcing it through its circle of rotation. The moment the propeller is permitted to progress, however, a new condition supervenes, and the thrust obviously cannot be higher than the restraining forces due to the resistances of the machine. This results in a speeding up of both aeroplane and propeller, to a point determined by the interrelation between the resistances of the machine and the power available to overcome them. This condition of balance reached, the working condition thereafter remains a uniform one.

The maximum thrust obtainable with any propeller, assuming an efficiency of one hundred percent, is very conveniently visualized by the simple assumption of a new unit, the "mile-pound," as compared with the "foot-pound." Thus a thrust of one pound, with a machine traveling a mile a minute, calls for the theoretical expenditure of 5,280 foot pounds per minute, equal to $\frac{5280}{33000}$, or, reduced to lowest terms, $\frac{4}{25}$ of a horsepower. On this basis, one horsepower can afford only 6.25 pounds thrust at 60 miles an hour, with an efficiency of one hundred percent—and proportionately less with less efficiency. Comparing this with the table of resistances on Pages 42-3, the very great significance of the elimination of head resistances by application of the "reaction impulse" will be readily appreciated.

PROPELLER MATERIALS

Most propellers so far built have been made of wood, this material combining lightness with strength in a degree that prevails with practically no metal capable of being as readily worked into the requisite forms. Formerly believed to be objectionable, the thickness of blade necessary to afford the requisite strength with wood, now, in the light of more complete understanding of stream-line forms, commences to appear as of positive advantage from other than structural standpoints. Nevertheless, once propeller design is reduced *to sufficiently* definite standards to warrant the expense *dies, it is* more than likely that propellers will be most s

actorily made of thin sheets of steel, concaved under heavy presses into the forms necessary for the working surfaces and the backs of the blades, and with the two pieces thus employed in each blade joined around the edges by autogenous welding.

BEARINGS AND LUBRICATION

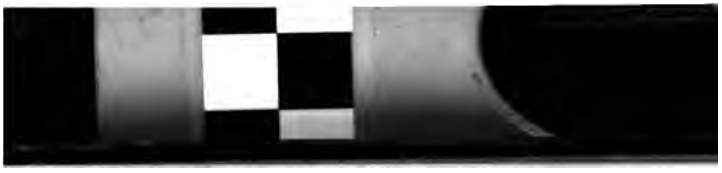
Most important elements in any mechanism are its bearings and their lubrication, since it is upon the integrity of the wearing surfaces and the minimization of power loss and wear induced by their friction that continued serviceability must depend.

BEARINGS

In the history of mechanism an immense variety of bearings have been devised to serve as great a variety of needs, but present-day engineering practice has settled upon a few long-tested types of ball, roller, and plain bearings as the most suitable for all ordinary purposes. Each of these different types has been proved to have its special merits, and, in most cases demerits, so a choice is usually dictated by the special conditions to be met.

For the present consideration, therefore, it is possible to do little more than generalize by emphasizing the importance of liberal sizes, liberal areas, and the best material in bearings, as the surest means of affording abundant strength and reliability, immunity from heating, and slow wear.

Ball Bearings, substituting rolling for sliding contact as a means of diminishing friction, are very old in their conception, but first came into general and practical use with the advent of the bicycle. Since then they have been widely developed for application to the automobile and, latterly, for the aeroplane. Ball bearings manifest their superiority most markedly in the reduction of the friction load at the moment the mechanism is started in motion, the starting friction when they are employed being practically no greater than the effort subsequently necessary to maintain the mechanism in operation against the running friction of its bearing. In the best types of plain bearings, in which running friction *often is reduced* to a very small fraction of the load transmitted, the friction load at starting is always vastly greater.



LUBRICATION

For mechanisms that must be very light and yet subjected to a maximum possible duty, as tends to be the case with practically all the elements of the power plants of aeroplanes as they are now made, it is a most pressing necessity that constant and adequate lubrication be automatically provided for every bearing, so that unfailing functioning may be reasonably assured with a minimum of attention. Haphazard methods of lubrication, which in a way can be made to serve in automobiles and other mechanisms, are under no circumstances to be tolerated in the design of an aeroplane power plant, in which the lubrication should be regarded as one of the most important elements of the whole design, and arranged for on a correspondingly adequate basis.

Lubricants found most suitable for aeroplane use comprise a range of mineral oils and greases similar to those preferred for automobiles. In addition to these, castor oil in liberal quantities has been proved to possess peculiar advantages for air-cooled motors with steel-to-steel wearing surfaces, while deflocculated graphite is commencing to receive recognition as possessed of meritorious qualities when admixed with neutral oils and greases.



CHAPTER EIGHT

AEROPLANE OPERATION AND NAVIGATION

Aeroplane use having already developed to the point where long cross-country and over-water trips have been undertaken, and in a majority of cases successfully accomplished, while the future promises vastly to increase the amount of long-distance journeying by air, questions of the developing technique of aeroplane operation and navigation are properly to be regarded as of increasing importance.

STARTING AND LANDING

Since the aeroplane flies by means closely analogous to the means employed by birds in gliding flight, the necessity for starting and alighting runs is apparent when it is considered that even the birds do not escape this necessity—small birds making their initial rise into the air by one or more hops, and larger birds being compelled to drop from an eminence or to make considerable runs on the ground before they can get into the air. It is an interesting but well-established fact, for example, that the condors and the California vultures, the largest flying birds known, can be securely imprisoned in small pens open at the top but with sides sufficiently high to require rather a steep angle of ascent.

PREPARED AREAS

For these reasons, as the successful flying machine comes more and more into practical use it must reasonably come to be recognized as quite natural for aeroplanes to require for their practical utilization the provision of special landing places and starting areas, just as it is commonplace for docks to be provided for water craft and stations for railway trains. Likewise, too, to make what seems a reasonable deduction from these considerations, it is probably a wholly erroneous idea of the factors of the situation to suppose that aeroplanes ever can be used for urban travel, such as must require their starting from or alighting in the streets of cities, *or even upon the* roofs of buildings—though it is possible



that the latter may in time come to be utilized to a greater or less extent. But the more likely immediately provision will be that of large cleared areas in the suburbs of towns and cities, with exclusively suburban flying between these areas, which will leave the problems of strictly urban transportation to other than aerial vehicles.

It seems impossible ever to escape the superior desirability of cleared areas from which to start and upon which to alight. Nor is it likely that such areas will suffice if merely made long and comparatively narrow, as has been often suggested. Preferably they will be circular, or large enough to include such a circle that ground travel in any direction will allow sufficient distance for the necessary retarding or accelerating. A minimum of a quarter of a mile in diameter would seem to be as small a circle as it is at present safe to consider, and in the case of such an area being bordered by trees or high buildings, such as might not be readily passed over at the steepest possible angle of ascent, the space should be extended considerably beyond that actually required for the mere run on the ground. The largest area absolutely required would be such as would permit a turn before the edge of it was reached, followed by circling flight over the field until sufficient height were attained to pass over the highest of adjacent obstacles.

WATER SURFACES

The recent development of hydroplane alighting gears makes it more than likely that small inland lakes and ponds may be in the future widely utilized as aeroplane stations, especially if the hydroplane alighting gear can be combined as successfully as seems probable, with wheels and runners that also will permit starting from and landing upon the ground.

INFLUENCE OF WIND

Facing the wind, while perhaps not an absolute necessity, is certainly a most desirable condition of starting and landing with present types of aeroplanes. Obviously, since aeroplane wings must be moved laterally through the air before they can lift a machine from the ground, in running into the wind the speed through the air is higher than the actual speed *over the ground*, with the consequence that only a low ground *speed is necessary* to secure the requisite air speed. C

versely, in starting with the wind there must be subtracted the speed of the wind from the ground speed of the vehicle, necessitating so high a ground speed as to render starting very difficult with the wind behind the machine, unless the wind be moderate almost to the point of calmness.

With a wind at the place of starting greater in its speed than the maximum flying speed of the aeroplane, starting is almost impossibly dangerous from every standpoint of present knowledge, because its attempt is almost certain to result in throwing the machine over backward.

A wind from the side is objectionable in starting and in landing, because it tends to careen a machine over and thus cause disaster.

Of course, once an aeroplane is in flight, it is a comparatively simple matter to turn and travel in any direction—with the wind, against it, or across it.

PROPERTIES AND PHENOMENA OF THE ATMOSPHERE

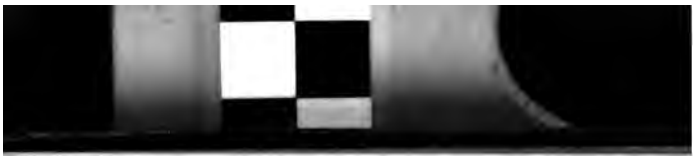
As the medium through which all aerial vehicles must travel and from which they must derive their support, at least a passing consideration of the properties and phenomena of the atmosphere has a logical place in a work of this character.

The weight of the air is an especially important consideration in the design of an aeroplane, since in any heavier-than-air apparatus the weight of it is sustained by the quantity of air acted upon and reacting, an interrelation that varies in the force of its effects with the area of the sustaining surfaces, the rapidity of the action, and the consequent mass of the air affected.

According to the best authorities, air not freed from water vapor and the other impurities usually present, weighs at sea level, at 32 degrees Fahrenheit, very close to .080728 pounds to the cubic foot—practically 12½ cubic feet to the pound.

Of the dynamic properties of air, the most important from aeroplane standpoints are its inertia, its elasticity, and its viscosity.

The most important meteorological phenomenon of air is the movement of the atmosphere in the form of winds.



INERTIA

Air in common with all other matter having weight exhibits the various phenomena of inertia, which may be defined as the tendency of a mass to remain at rest, or to continue in uniform motion in a straight line, until acted upon by some disturbing or retarding force. Naturally, air being invisible as well as much lighter than solid or liquid forms of matter, its inertia is less marked than in the cases of most heavier substances. But that under favorable conditions it is a quality to be reckoned with is abundantly proved by the very fact of human flight itself, as well as throughout a great range of natural phenomena, from the flight of birds to the extraordinary vagaries of cyclones.

As one great investigator has tersely expressed this profound aerodynamic truth in form to be appreciated by the man in the street, "the air is hard enough if it is hit fast enough."

ELASTICITY

The property of elasticity is one of the fundamental qualities that distinguish air from liquids. Air and other gases are in fact the only perfectly elastic substances known—the only substances that will withstand compression to an indefinite extent and for indefinite periods without in the slightest degree losing their ability fully to recover the original volume. Gases compressed to thousands and even hundreds of thousands of pounds to the square inch, for no matter how long a time, instantly and unfailingly expand to any extent permitted by release of the pressure.

It is to a great extent this property of perfect elasticity that, under favorable conditions, makes for the exceptionally high efficiencies that can be realized with suitably designed mechanisms for operating on masses of air.

VISCOSITY

Viscosity is a property of fluids closely comparable to the cohesion of solids, and may be defined as the tendency of the molecules to occasion friction when driven against or past one another. The viscosity of air is generally stated by investigators to be much higher than that of water—not per unit of volume but per unit of weight. From the standpoint *of the practical* aeroplane designer, this viscosity imposes *drag upon all* elements of the machine, opposing increasi

resistances to their movement as the speed of such movement rises, the increase generally being stated to vary with the square of the speed, though at very high speeds it probably increases in some higher ratio. The question of skin friction on aeroplane and propeller surfaces thus is simply a matter of the viscosity of the air.

WIND

Winds, amounting simply to more or less rapid movement of portions of the atmosphere with relation to the earth's surface, present many aspects of interest to the air navigator, and are worthy of his profoundest consideration.

Atmospheric movements vary in direction, velocity, and duration, and in the presence of ascending or descending components, and are classified according to their velocity, direction, and duration into the different classes of storms and winds.

Wind velocities vary from those of most imperceptible zephyrs to the immeasurable violence of the cyclone. The highest winds that have been successfully recorded by anemometers are slightly in excess of 100 miles an hour.

Ordinarily wind velocities average much lower. In 650 different daily observations of wind movement over the five great oceans, taken on board the "Challenger" during a 3½ years' cruise that ended in May, 1876, the mean hourly wind velocity was 17 miles. In 552 observations taken on land during the same period the mean hourly velocity amounted to only 12½ miles.

Wind velocities are much greater at high altitudes than lower down. Kite experiments in a wind of 22½ miles an hour at the surface have on at least one occasion indicated a velocity of over 130 miles an hour at a great height. Very moderate heights are enough to cause a considerable difference, and observation will often show a wind velocity of twice that at the ground, at a height of no more than 50 or 60 feet.

Besides major changes in velocity and direction, winds are subject to a multitude of minor variations and fluctuations, almost from moment to moment, especially in proximity to terrestrial irregularities, which retard and deflect them and otherwise interfere with their free sweep. Recording instruments show that such fluctuations are often quite

incessant, occurring with great frequency and throwing the air into billows and whirls and irregularities—which to cope with safely is certainly to be regarded as one of the more serious problems of aerial navigation.

Ascending components in apparently horizontal winds, and especially in those blowing over horizontal surfaces, have occasioned much discussion and speculation by students of aerial navigation because of the supposed bearing upon the sustained soaring flight of certain birds.

It is evident that indefinite progress in a horizontal direction might be made with a gliding aeroplane, were the air continuously rising. Rising currents are now attributed to two principal causes—one, the slant of irregular country over which winds may blow, and the other, over flat country, the retarding friction of the lower strata of air on the surface.

Another class of rising currents is that due to heating of the air. Chanute is authority for the statement that such vertical currents, seemingly unaccompanied by adjacent horizontal currents, may flow as fast as from six to ten miles an hour.

HEIGHT OF FLYING

Much speculation has been indulged in by the lay mind concerning the heights at which the average flying of the future is likely to take place, if aerial navigation is to become the factor in the world's affairs that is so confidently predicted for it by so many.

ELEMENTS OF SAFETY AND DANGER

A casual analysis of the question is sufficient to indicate that both flying high and flying low possess their peculiar dangers and advantages. Thus flight close to the ground is more likely to cause falls, but these are less likely to result seriously, whereas in high flight there is little danger of falling, but in case falling does occur there is almost the certainty of a dreadful result.

The reason for this condition has been referred to in previous pages, it being simply a matter of the air being steady and uniform in its movements at high altitudes, whereas close to the ground it is disturbed and thrown into invisible billows and breakers by the obstacles over which it flows.

As far as the mere matter of control is concerned, after aviator, even with present-day machines, has strated an almost unfailing ability to maintain a fixed from the ground very closely—skimming along just the earth's surface, at a constant height of only a fe or keeping closely to given altitudes by barometer ob tion in flying at greater heights.

NAVIGATION

Aeroplane development can scarcely be said as yet to h progressed to the point of providing the air navigator w as completely formulated rules for keeping his course, and efficient adjuncts and devices for air navigation, as have be developed for the mariner by centuries of water navigatio yet much good work in this direction has been done, an more is under way.

MAPS

Considerable activity exists in the military departments of several European governments in preparing special maps of the earth's surface for the use of men traveling above it in the air. The best of these maps are printed in colors simulating the actual appearance of the ground as it is seen from above, roads being white, forests green, water surfaces blue, etc. For convenience of handling, maps in the form of long, narrow bands, mounted on rollers that can be fed by hand as the country is traversed, are most favored by the European military officers experienced in cross-country flying.

THE COMPASS

The use of the magnetic compass to maintain a desired orientation of an aeroplane is beset with far greater difficulties than are involved in its similar applications to the navigation of water craft.

The disturbances produced by the presence of iron and eel parts in the neighborhood of an aeroplane compass can minimized as in marine engineering by the removal of ch parts to the greatest possible distance from the com- s and the balancing of the residual magnetic effect by the cing of masses of soft iron in suitable neutralizing posi- s. *But* the disturbing influence of cross winds, occasion- *eeway so* great as to carry a machine dozens of degrees

out of its course in spite of its being kept constantly pointed in the desired direction, is a condition that does not prevail in water navigation, in which the drifts due to the greatest and most rapid ocean currents are so slight as to require only very small allowances to be made for them.

THE DIPPING NEEDLE

When the day of transoceanic aerial navigation arrives, as it seems almost certain that it must arrive in the near future, it is possible that the dipping needle—which is simply a compass set to swing in a vertical plane—can be made use of to indicate such serious deviations from a given latitude as would result from getting greatly out of an east or west course. It is the property of the dipping needle to stand vertically at the magnetic poles of the earth and horizontally at the equator, and to point at intermediate degrees at intermediate latitudes. The dipping needle is subject, however, to variations similar to those of the compass, and the vibration and rocking of aerial vehicles will not tend to simplify its practical application.

THE BAROMETER

A barometer carried on an aerial vehicle serves two purposes—of indicating altitude and of forecasting weather changes. In either case the barometer is simply a pressure gauge, showing the atmospheric pressure at any given time.

In aneroid barometers the air pressure is indicated by the action of the pressure against the thin metal sides of one or more flat vacuum chambers, made of thin, elastic, metal disks, between which springs are placed to resist the pressure. A simple multiplying device converts the very slight movement of the vacuum-cell walls into the more ample movement of a hand around a circular dial or across a recording surface.

TERRESTRIAL MARKINGS

The use of markings placed on the earth's surface so as to be visible to aeroplane drivers overhead, has been the subject of extensive experiments in Europe. One of the first attempts in this direction was the whitewashing of the railway lines between London and Manchester so that Paulhan should *not miss his course* at the junctions, in his memorable flig *between these* two English cities.

Later developments in this direction have been the v
plans proposed and experimented with in France for di
that country into rectangular sections, and placing thr
out each section indicating numbers from which the lo
could be instantly recognized. Experiments conducted
the Eiffel tower have shown that white numbers one m
high (39.37 inches) on black backgrounds are quite read
in all ordinary atmospheric conditions from distances
several thousand feet.

Very suggestive of what may be required was Atwoo
policy in his flight from St. Louis to New York City, of flyi
low past the railway stations to read the names painted up
them.

SPEED AND DISTANCE INDICATORS

The determination of speed and distance traveled through the air by an aeroplane is a comparatively simple matter, and it is probable that more effective and reliable for this purpose than even the various anemometers and speed indicators that have been devised, will be the use of simple revolution counters for application to the shaft of the propeller, which, according to its pitch, definitely advances so many feet for each revolution, and thus can be depended upon to maintain very closely a uniform tally upon progress through the air, once the counting device is properly calibrated. It is almost universal practice in marine engineering for the progress of steam vessels to be similarly logged by revolution counters on the propeller shafts.

The matter of speed over the land, however, is another and more difficult problem, since it is influenced by the question of wind, which may cause the whole body of the atmosphere to move with the machine, thus adding wind speed to aeroplane speed; against it, subtracting wind speed from aeroplane speed; or across its line of travel, with the effect of producing smaller modifications in the land speed. Apparently the only possible means of keeping a check upon these disturbing factors will be to use methods of "dead reckoning," which are likely to prove no more than indifferently liable.

NIGHT FLYING

Flying at night already has been practiced to some extent *few adventurous* aviators, at least one or two of whom

have gone aloft with acetylene lamps arranged to project searchlight beams upon the surfaces beneath them.

As aeroplane navigation develops it unquestionably will become necessary to have in addition to powerful lights on the machines themselves lights and signals visible from the ground at night, to correspond with the markings that will be used for flying in the day time.

RULES OF THE ROAD AND LAWS OF THE AIR

In common with all types of land and water vehicles, there is the necessity with the vehicles of the air for the establishment of rules and laws to govern aeroplane operation, so that it may be conducted with a maximum of safety.

Already the governing bodies in control of aeroplane competition throughout the world have formulated a few general "rules of the road," such as those prohibiting the passing of machines closer than at certain stated intervals from each other—it having been discovered that the "wash" from one machine often has a serious tendency to upset or reduce the lift of another adjacent to it.

The laws of the air, which are just commencing to be legislated into existence, are at present concerning themselves chiefly with restrictions in regard to operators and machines, with the plan of demanding competence, quality, and sound design. As time goes on, these first crude attempts at legislation will develop into codified provisions for the licensing of pilots, definition of conditions and restrictions upon national and international flight, and stipulation of arrangements of lights and systems of signals, such as will tend to render aerial traffic of such well-ordered type that the machines in the air will be of the smallest possible danger and of the greatest possible help to one another.

GENERAL CONSIDERATIONS

It seems proper here to emphasize the fact that neither the construction nor the operation of the best modern aeroplanes call for the uncommon knowledge and expertness they are popularly supposed to demand, unless there be involved the attempt to devise something new rather than to copy *something tried* and tested. Rather than much knowledge *the construction* of an aeroplane along established lines

While aeroplane accidents
ignorance, they more of
which while it may be co
rance, is a phenomenon of
place whatever in aeropla
mistaken for courage.

The initial practice flig
chine should never under a
the slightest wind, or els
and very uniform surface
the ground flight while av
terrestrial obstacles.

CHAPTER NINE

THE FUTURE OF FLIGHT

The wide introduction of aerial vehicles into the hands of the general public cannot fail to exert consequent influences of the profoundest importance upon nearly all phases and regulations of the present social order.

The very independence of movement which only an aerial vehicle can possess must in itself unfailingly modify the whole structure of civilization, if present expectations of flight engineers concerning safety, carrying capacity, speed, economy and efficiency, utility, and other qualities are in any considerable degree realized.

SAFETY

The question of safety is ever uppermost in most persons' contemplations of aerial travel. To the average individual the very mention of an aeroplane now involves immediate visualization of an unstable craft of vague outlines and terrible hazards, precariously poised in the cloudlands at an illimitable height above terra firma. But how completely such ideas are at variance with the fact is shown by the circumstance that aviation has proved less dangerous, for a given number of persons engaged in it, than college football, or, for a given number of miles traveled, than automobile racing.

In the future, however, this safety is certain to be much improved. Indeed, the ultimate safety in aeroplane operation is far greater than might be supposed from obvious comparisons. This is because, while land vehicles are built to travel on land, they are built to do so only on specially-prepared courses, so that when an automobile leaves the road, or a rail vehicle leaves the rails, imminent and terrible dangers are at once introduced. On the other hand, in the case of the vehicle designed to travel in the air—even a *plunge to the earth* involves movement through rather th

away from its natural route, with a corresponding chance that remains, if the vehicle be well designed, of regaining its normal control and recovering its equilibrium without injury to its occupants.

The fact that precarious and ill-designed machines have been extensively built, and have been operated by men more reckless than competent, does not gainsay these facts.

How totally in error is the popular conception is sufficiently manifest in the general opinion that motor failure always results in a fall, whereas to the direct contrary, the ability of an aeroplane to soar reliably at a flat angle down a slant of air is contingent only upon the continuous structural integrity of non-moving structural elements, or at the worst, of control elements made very strong or even provided in duplicate, and demanding only moderate and occasional adjustment against very light stresses. Engine failure therefore compels a descent rather than results in a fall, while with the duplication of motors that may be a feature of future development, it cannot even compel the descent—which in any case would be harmless unless all the surface beneath were desert or forest or rough mountains, or an extent of water so great that the small boatlike or floating structure would not be a sufficient protection against ultimate disaster.

A condition making for safety in future machines may be the division of the duties of operation between a pilot or steersman and a motor attendant, each independent, though in convenient communication with the other.

SIZE AND CARRYING CAPACITY

The sizes of the machines that will be built in the future is another matter that must be left for the future to determine. It being a law of geometry already referred to that the areas of structures increase with the squares of their linear dimensions, while bulks and weights increase with the cubes, it is evident that at some point the gain of the weights over the areas will impose the limit that cannot be passed.

Discounting this, however, is the probability that there will not be much demand for large air craft. Traffic experts invariably agree that the secret of all rapid transit is the *maintenance* of rather than the capacity for speed, it being *the slowing* down and stops that chiefly account for the low



average speeds on land, despite the wonderful bursts of speed that have been made by land vehicles for short distances. And most evidently the existence of the expensive large unit vehicle on land is due mainly to the necessity for highly specialized, prepared highways, while on water it has been found an essential means to high speeds and maximum safety.

In the air, conditions will be different. Here the inexpensive and ideal small-unit vehicle, suggested in a great degree by the automobile, and similarly emancipating its users from other person's routes, stops, and time schedules, will find an unlimited field for development.

SPEED AND THE RADIUS OF ACTION

The questions of speed and the possible radius of flight without landing are still a long way from settlement. Certainly the speeds ultimately to be obtained with aeroplanes will be very high, but, what is more to the point, they will be easily maintained. In this regard aerial navigation is comparable with travel on water rather than with travel on land, maximum speeds being also average speeds in the case of power-propelled water craft, a condition without parallel in the field of land locomotion.

In addition to its other advantages, high speed of aerial travel is the soundest engineering, because it admits of sustaining the greatest loads upon the smallest surfaces.

Another and imperative reason for speed is to overcome adverse winds. To progress against winds, speeds higher than the velocities of the highest winds in which flying is to be attempted must be available.

The limit of wind velocity with which it may prove possible to travel will be determined mainly by conditions of starting and landing.

As for the possible radii of action—the maximum distances of travel without return to a base or descent to the earth for additional fuel, lubricant, and other supplies—it is possible to do little more at present than to generalize, with the statement that the greater the radius the greater the utility.

Indeed, the ability of the aeroplane to combat long-continued adverse winds, its application to polar and othe exploration, transoceanic travel, and sustained rapid tran

over land, will hinge largely upon the capacity to accomplish great distances on a minimum of supplies and fuel.

The chief limitation at present in the way of long-sustained flight—barring, of course, the matter of more or less violent storms in which flight cannot be safely attempted, and the question of providing for alternative operators, is the difficulty of carrying sufficient supplies of fuel. From this it must be clear that as there are developed more efficient propellers and engines, and surfaces affording higher sustentions with smaller forward resistances, the radii of action will be increased in proportion.

In the case of water travel, except in some instances of river navigation through rapids or channels in which streams move with a rapid flow, the currents in navigable waters are not of sufficient speed materially to help or to hinder vessels passing through them. With the atmosphere the case is quite the other way. In this lightest of earth's traversable media, movements of air in the form of winds of velocities considerably in excess of the best speeds that have been attained with aeroplanes are common. Winds of even as high as one hundred miles an hour—approximately as fast as the greatest present aeroplane speeds—are occasionally to be reckoned with, though such velocities are not commonly encountered at the level of the earth's surface.

Remarkably fast flights across country have been made by European aeroplanes, in which to the speed of the machine was added the speed of the wind. In several of these flights a curious condition was observed to result from the fact that wind velocities are generally greater at heights above the ground than they are at lower altitudes. This condition is found to admit of starting an aeroplane from the ground in a moderate wind, followed by a wholly imperceptible progress as it gradually rises, into winds of greatly higher velocities at greater heights. The transition into these winds of higher velocity is so gradual as to be quite unnoticeable, there being practically an infinity of superimposed strata, each moving a little faster than that below, with the whole effect substantially equivalent to that of the more or less common moving-sidewalk schemes, in which a passenger progresses from one to another of a series of moving platforms, the first moving *slowly and* the last at high speed, but with the relative speed

between any two adjacent platforms so moderate that it is easy to step from one to the other without jar or danger.

ECONOMY AND EFFICIENCY

When reduced to standard forms, aeroplanes will be inexpensive to build because their construction will call for little use of complex forms in resistant metals. Wood, wire, and fabric, of common qualities and at low costs, are almost the extent of what is necessary, barring the question of motors, which in the future will be required in smaller power units than at present, and which will be cheaply manufactured in quantities to standardized designs.

Even more vital than mere low cost of manufacture will be the fact that aeroplane manufacture will not require the facilities of costly factories, but can be undertaken by any one possessed of the requisite data and an ordinary sort of carpentering ability.

That flying machines will be inexpensive to operate must reasonably follow from the small power required for their propulsion and from the fact that they have no working parts in constant destructive contact with a roadway.

Indeed, the transition from confining air in automobile tires to the utilization of the unconfined air of the atmosphere as a vehicle support, is rather definitely an advance from a lower to a higher order of engineering.

Concerning maintenance cost and the cost of operation, with some of the most efficient modern aeroplanes it is even now possible to transport weights of over 1000 pounds for distances of twelve or fifteen miles upon a gallon of gasoline —a result comparing most favorably with even the best secured with modern automobiles, especially at anything like similar speeds.

UTILITY

An inevitable result of low first and maintenance costs must be extensive acquisition of aeroplanes by all manner of individuals—by individuals of a class to-day hardly able to afford even the most inexpensive automobiles. Further contributing to this condition is the fact that an aeroplane is not confined to roads or highways of any kind, rendering quite remote the possibility of monopolies, or limitations in their

use other than the direct physical limitations at present imposed by such mechanical imperfections as at present exist, but which will be greatly minimized in the future.

The first commercial application of flying vehicles will most likely be to the transport of light commodities, such as it is desirable to convey at great speeds, and which therefore can be charged for at high rates per unit of weight. The ideal service of this character would be that of a number of vehicles traversing a route of the maximum distance possible to accomplish without alighting, dropping mail bags or the like on clear areas where watchers would be waiting to receive them.

The question of aerial travel over water is one of particular significance, especially in the light of the recent development of the hydroaeroplane. Water areas, in common with the atmosphere, possess a quality which does not pertain to land—the quality of uniformity. The consequence is that transaquatic mail lines utilizing aeroplanes provided with hydroplane floats can be conducted with almost perfect safety without necessarily involving flight higher than just above the wave crests. It is quite to be anticipated that the institution of some such service over routes marked by regularly-spaced patrol boats may constitute the first serious commercial exploitation of the aeroplane. A special incentive to experiments in this direction is the low speed of even the fastest present water travel, by contrast affording to the flying machine an advantage that it does not yet possess in comparison with the higher speed of land travel.

In the matter of limitations, it certainly is to be admitted that the aeroplane appears totally unsuited for urban travel. In its present form it requires the considerable clear and unobstructed areas for starting and alighting, which are rarely available, and then only at infrequent and often inconvenient intervals, in cities.

For interurban travel, on the other hand, this difficulty rarely applies, and there is no more reason for expecting the aeroplane to find its field by a facility in maneuvering through mazes of wires and in alighting amidst street traffic than there would be for condemning Atlantic liners because they have to dock at Hoboken instead of sailing up Broadway.

Undoubtedly the time will come when it will be considered *quite as reasonable* for the beginnings and endings of aerial

voyages to involve the presence of special launching and alighting facilities, as it is that railway trains should travel from station to station.

No type of transportation is unlimitedly flexible. Rail vehicles are confined to rails, automobiles must keep the road or to good surfaces, water craft cannot leave the water, bicycles require at least a fair path, and not even beasts of burden and men walking can disregard all topographical difficulties. Against these, surely the ability of the air vehicle to progress in an air line at its high and maintained speed from selected starting points to selected destinations, ever regardless of what may be beneath, and ever ready when necessity may compel to settle under control and without immediate danger upon any fair area of unencumbered land or water space, may be regarded as a form of flexibility sufficiently valuable to offset the lack of other sorts.

APPLICATION TO WARFARE

Particularly interesting is the relation of aerial navigation to war—it appearing more than probable that this latest of man's inventions may serve first in adding to the terrors of, and then in the laying of this grim specter of the centuries. For in this modern age, success in waging war depends chiefly on the perfection and utilization of machines for the destruction of life and property. Indeed, modern warfare is essentially a manufacturing proposition—a cold-blooded problem of economically manufacturing corpses out of the enemy's men and ruins from his material possessions. Thus considered, in the development of the flying machine there is placed for the first time in history, in the hands of weak and strong combatants alike, a terrible and effective weapon capable of as unpreventable direction against the kings, congresses, presidents, and diplomats who declare war, as it is of direction against the fighting men on the remotest seas and far-away battle fronts.

Already more than one great military and naval captain has suffered disquieting visions of what will happen when, maneuvering unopposed and unseen in the obscurity of the night, not merely one or a few, but veritable swarms of aeroplanes, in flotillas of twenty thousand costing no more than single dreadnoughts, will commence dropping bombs or trailing assortments of high explosives at the ends of thousand-

foot lengths of piano wire, over cities and palaces and through fleets and armies.

While it is true that the aeroplane seems to have only one method of attack open to it—the dropping of dangerous combustibles and high explosives as accurately as may prove possible into the weakest and most vulnerable points in the enemy's military and social organization—this method, as speculation upon it is indulged in, becomes sufficiently horrifying to appall the most skeptical tactician or hardened soldier.

Undoubtedly the initial points of attack would be on the seas the enormously-costly mechanisms—the battleships, cruisers, and torpedo boats—of modern navies, which even to-day seem open to destruction should occasion demand, by very ordinary application of the capabilities of such aeroplanes as have been developed—working, it is to be emphasized, not individually, but in fleets, with results that seem quite inescapable.

On land the points of attack might be the storehouses of military and food supplies, or even the property in great cities, which, all action of peace congresses and international tribunals to the contrary, it is very likely that a determined and aggressive foe hard pressed would ultimately assail, after issuing due warnings commanding immediate removal of all non-combatants—such warnings to be disregarded at the peril of the party attacked. For in the last analysis of the bitterness of conflict between militant nations, wars are fought less by rules than to win victories.

Many authorities are inclined to disparage the fighting utility of the aeroplane, basing their views on the fact that it has been demonstrated fairly difficult to drop bombs with any considerable accuracy from great heights. But at the termination of a *volplane*, at the moment when the speed of the aeroplane is temporarily checked, it should be an easy matter for skillful pilots to cast generous parcels of fulminate of mercury or picric acid into the twenty-foot diameters of a battleship's funnels, or a can of igniting gasoline over a conning tower. And the answer that such an attempt would be foiled by the use of searchlights and quick-firing guns is one that can contemplate attack by only one or two aeroplanes, *rather than* the concerted descent of a whole host of such *emissaries of* destruction, each manned by a competent and



determined crew, conscious that the individual's risk is small and the chance for glory great—realizing that if only one of the wasplike swarm achieves its purpose the picking off of a few by lucky shots or extraordinary gunnery will be fearfully avenged.

Almost as significant as its power for destruction is this invulnerability of the aeroplane. Though aeroplanes are without armor or any corresponding protection, yet, operated in fleets, and if necessary under cover of the night, no one familiar with modern gunnery or the use of firearms needs to be told how utterly difficult and impracticable will be found all schemes for winging the aerial vehicle.

It is difficult enough to hit a fixed target with substantially-mounted weapons after the range has been accurately found. It is more difficult to strike a moving target on the ground, or afloat on the water, though even in these cases the restriction of the movement to a horizontal plane, and the possibility of correcting errors in the determination of the range by dust thrown up by the projectiles, or by their splash in the water, is a great help.

But to strike a vehicle moving through the air, capable of extraordinary celerity in maneuvering, capable of three-dimensional travel—up and down as well as in all lateral directions—and with no means whatever of finding range, can never happen except by the purest of pure accidents. And when it does happen its effect upon the enemy's strength is so certain to be so utterly trivial—involving the destruction of no more than a few hundred dollars' worth of machinery and the lives of not more than one or two individuals —that its futility as a means of winning a victory is almost too evident to require discussion.



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